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Dental age estimation using the tooth coronal index (TCI) method in an Indonesian adult population *

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Abstract

Background: The Tooth Coronal Index (TCI) was widely applied in forensic odontology for dental age estimation, based on the inverse relationship between chronological age and the size of the coronal pulp cavity. This study aimed to evaluate the difference between chronological age and dental age estimated using the TCI method in adults. Materials: This study utilized orthopantomograms from 100 patients (50 male and 50 female) who met the inclusion criteria. Methods: This retrospective cross-sectional study analyzed 100 digital panoramic radiographs (50 male and 50 female) that met predefined inclusion criteria. Crown height (CH) and coronal pulp cavity height (CPCH) of mandibular first molars were measured using ImageJ software. TCI values were calculated as (CPCH × 100) / CH. Dental age was estimated using a regression-derived equation. Statistical analyses included normality testing, homogeneity assessment, pair t- test, and R2 analysis. Result: Chronological age data were not normally distributed, whereas dental age data followed a normal distribution. The homogeinity test results indicated that chronological age and dental age did not exhibit a significant variance difference. Pair t-test analysis demonstrated not significant difference between chronological age and dental age. The contribution (R2) of TCI to chronological age was only 0.010, while the remaining variance was explained by other factors. Conclusion: TCI showed minimal predictive value for chronological age, and no significant difference was observed between chronological age and dental age. These findings suggest that TCI alone is insufficient for accurate age estimation and should be complemented with additional indicators in this population.

Keywords: chronological age; dental age; TCI method

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Introduction

Forensic odontology played an essential role in human identification, particularly in situations involving severely decomposed, burned, or skeletonized remains. Teeth were among the most resilient tissues in the human body due to their highly mineralized composition, allowing them to withstand thermal and chemical insults better than most biological tissues. Age estimation constituted one of the primary responsibilities of forensic odontologists and had implications for humanitarian identification, medico-legal processes, and demographic assessments in both living and deceased individuals. In the absence of reliable birth records, dental structures provided stable biological markers that supported chronological age estimation (1).

Panoramic radiography was frequently used in forensic age estimation because it provided a comprehensive view of the maxillofacial region with relatively low radiation exposure. This modality enabled clinicians to evaluate tooth mineralization patterns and pulp chamber morphology, both of which reflected age-related physiological changes (2).

By the early 20th century, investigators had recognized that secondary dentine deposition continued throughout adulthood, progressively reducing the size of the pulp chamber. This regressive change provided a measurable biological marker that could be visualized radiographically and was distinct from developmental indicators commonly applied in children. The observation that pulp chamber dimensions diminished with age ultimately established the conceptual basis for radiographic age-estimation techniques (3).

The concept of the TCI originated from the seminal work of Ikeda et al. (1985), who first proposed a quantitative radiographic approach for estimating adult age based on the reduction of the coronal pulp cavity. Prior to their study, age estimation in adults relied largely on qualitative assessments of secondary dentin deposition or histological methods, which were invasive and lacked standardization. Ikeda and colleagues were the first to demonstrate that age-related changes in the pulp chamber could be expressed as a measurable ratio derived from routine dental radiographs (4).

Their method quantified two anatomical parameters: crown height (CH) and coronal pulp cavity height (CPCH), measured from the cemento-enamel junction to the highest cusp and to the highest pulp horn, respectively. The resulting formula, TCI = (CPCH × 100) / CH, showed a consistent negative correlation with chronological age, confirming that progressive secondary dentin deposition reduced CPCH over time (5).

Ikeda et al.'s findings established the first standardized radiographic index for adult age estimation and laid the theoretical foundation for subsequent refinement by Drusini and others in the 1990s. The 1985 study thus represented the earliest and most influential contribution to the development of TCI, forming the basis of its continued use in modern forensic odontology (6).

In recent decades, the TCI gained wide acceptance due to its practicality, minimal ethical concerns, and cost-effectiveness. Unlike invasive histological or biochemical methods, TCI relied solely on standard dental radiographs, making it applicable to both living individuals and skeletal remains. Rooted in early research on secondary dentin deposition and formally developed during the 1980s, the TCI remained one of the most valuable and widely used tools in forensic odontology for adult age estimation (7)

Although TCI offered advantages such as simplicity, non-invasiveness, and low cost, its accuracy varied across populations and radiographic modalities. This study investigated the discrepancy between chronological age and dental age estimated using TCI in adults aged 25–45 years in Indonesian population

Materials and Methods

Study Design and Ethical Approval

This retrospective cross-sectional study was approved by the Health Research Ethical Clearance Commission of the Faculty of Dentistry, Universitas Brawijaya (Approval No.010/UN10.F1301/KEPK-FKGUB/EC10/2024).

Sample Selection

A total of 100 high-quality digital panoramic radiographs, obtained in 2024, were selected from the Radiology Laboratory of Faculty of Dentistry, Universitas Brawijaya. Inclusion criteria consisted of:

1. adults aged 25–45 years;
2. complete medical records containing sex, date of birth, and radiograph date;
3. clear visualization of the mandibular first molar;
4. absence of pathology or restorations affecting measurement sites.

Equal numbers of male and female subjects (n=50 each) were included to ensure balanced representation.

Measurement Procedures
Chronological age was calculated from the date of birth and the radiograph acquisition date. Dental age estimation followed standardized TCI procedures:
• Crown height (CH): distance from the cementoenamel junction (CEJ) to the highest cusp tip.
• Coronal pulp cavity height (CPCH): distance from the CEJ to the highest pulp horn.
All measurements were performed using ImageJ software. To ensure reproducibility, the examiner repeated measurements twice at separate time points.
TCI values were calculated as:
TCI = (CPCH × 100) / CH
A linear regression model generated the dental age estimation formula:
Dental Age = 30.173 + (0.101 × TCI)

Statistical Analysis
The intraclass correlation coefficient (ICC) was calculated to assess the reliability and agreement between measurements. Normality was evaluated using the Kolmogorov–Smirnov test due to the sample size (n = 100). Homogeneity of variance was assessed using Levene's test. As the chronological age data followed a normal distribution, a paired t-test was performed to compare chronological age and dental age. The level of statistical significance was set at $\alpha = 0.05$. In addition, the coefficient of determination (R^2) was computed to evaluate the strength of the relationship between the variables.

Results
The intraclass correlation coefficient (ICC) analysis demonstrated an excellent level of agreement between measurements. The ICC based on a two-way mixed-effects model with a consistency definition showed a value of 0.931 for single measures, with a 95% confidence interval ranging from 0.900 to 0.953, indicating that the measurement reliability was highly robust (Table 1).
The normality of the variables was assessed using the Kolmogorov–Smirnov (K-S) test. The results showed that chronological age demonstrated a statistically significant deviation from normality (K–S = 0.096, p = 0.025), indicating that its distribution was not normally distributed at the 5% significance level. In contrast, dental age exhibited no significant departure from normality (K–S = 0.078, p = 0.143), suggesting that the variable was normally distributed based on the test criterion (Table 2).
Levene's test was conducted to examine the homogeneity of variances between the groups. The test results indicated that chronological age did not exhibit a significant variance difference (Levene's Statistic = 0.306, p = 0.581), suggesting that the assumption of homogeneity was satisfied. Similarly, dental age also showed no significant variance inequality (Levene's Statistic = 2.075, p = 0.153) (Table 3).
The paired-samples descriptive statistics showed that, at the overall sample level (Pair 1), dental age and chronological age had almost identical means (33.23 vs. 33.22 years; N = 100), with relatively large standard deviations (≈5.8 years), indicating substantial inter-individual variability in age but no obvious mean difference between the two measures.
When the sample was split by sex, a similar pattern was observed. Among males (Pair 2), mean dental age was 33.30 years, whereas mean chronological age was 33.74 years (N = 50), again suggesting only a small difference relative to the standard deviation (≈5.8 years). Among females (Pair 3), mean dental age was 33.15 years and mean chronological age was 32.71 years (N = 50), also indicating closely comparable central tendencies. Overall, these descriptive results suggested that dental age estimates closely paralleled chronological age across the total sample and within both sex subgroup (Table 4).
The regression model showed a very weak association between TCI in total sampel score and chronological age as reflected by an R2 value 0,010, male sample as reflected by an R2 value 0.009 and female sample as reflected by an R2 value 0,070 (Table 5).

Discussion
The findings of this study showed that dental age estimates obtained through TCI closely corresponded to chronological age at the descriptive level. In the total sample as well as in the sex-based subgroups, the mean values of dental age and chronological age were nearly identical, and the observed differences were relatively small compared to the large standard deviations. These results indicated that, on average, age estimation using TCI did not systematically overestimate or underestimate chronological age. The similar patterns found among male and female participants further suggested that sex did not substantially influence the consistency between the two measurements. However, the regression analysis showed that TCI had very low predictive power for

chronological age. The regression models produced extremely small R^2 values—0.010 for the total sample, 0.009 for males, and 0.070 for females. These values indicated that TCI accounted for only about 1% of the variability in chronological age in most groups, and up to 7% in the female group. Such weak associations suggested that TCI was not sufficiently sensitive to capture individual differences in age. The slightly higher R^2 in females may have reflected certain biological variations related to secondary dentin deposition, but the value remained too small to consider TCI a reliable age-estimation method.

The contrast between the close similarity in mean dental age and chronological age values and the weak predictive capacity of TCI highlighted an important distinction between group-level agreement and individual-level accuracy. In this study, TCI produced estimates that aligned well with group averages but failed to explain inter-individual variability within the sample. This observation was consistent with previous research reporting limited accuracy of TCI, particularly in adult populations where secondary dentin deposition may be influenced by multiple biological and environmental factors.

Overall, the results suggested that although TCI was able to reflect general age trends at a group level, its utility for precise chronological age estimation in forensic or clinical contexts remained limited. Therefore, TCI should be complemented with additional morphological or radiographic indicators to enhance the accuracy and reliability of age estimation.

In other studies, with differing results, such as Yulianti et al study, which focused on the Banjar population, no significant difference was found between age estimation using the TCI method and chronological age (8). Research by Woroprobosari et al that investigated the applicability of the Benindra modification of the Tooth Coronal Index (TCI) for estimating biological age from mandibular first premolar using periapical radiographs at Sultan Agung Dental Hospital in Semarang. The results showed a narrow mean difference of 0.46 years between estimated biological age and chronological age. Among the samples, 43.5% were accurately estimated, while 30.4% were underestimated and 26.1% were overestimated. The method demonstrated good precision in both males and females, although males exhibited a slightly larger estimation gap (9).

Research by Yolanti et al that analyzed mandibular first molars were measured to calculate TCI based on secondary dentin deposition and pulp cavity dimension revealed revealed that the mean difference between chronological age and dental age was 6.3 years, with dental age exceeding chronological age. The results therefore suggested that TCI-based age estimation tended to overestimate chronological age in this population (10).

Research by Astuti et al that evaluate the applicability of the TCI method for estimating biological age from mandibular premolar using orthopantomography in the Malang City population showed a mean difference of ±1.32 years between biological and chronological age, with no statistically significant difference ($p = 0.11$) (11).

Abdinian et al investigated the reliability and accuracy of the Pulp/Tooth Ratio (PTR) and Tooth Coronal Index (TCI) methods for dental age estimation using digital panoramic radiographs. A total of 237 radiographic images of mandibular first and second molars from individuals aged 17–60 years were analyzed. Both PTR and TCI were measured and the estimated ages were compared with chronological age using statistical correlation and regression models. The findings demonstrated significant negative correlations between chronological age and both PTR and TCI indices, with PTR showing stronger correlations ($r = -0.890$ for first molars and $r = -0.788$ for second molars) compared to TCI ($r = -0.587$ and $r = -0.242$, respectively). PTR achieved higher accuracy levels (79.21% and 62.09%) with lower mean absolute error values (1.0 and 3.2 years), while TCI resulted in lower accuracy rates (34.45% and 5.85%) and higher error values (6.1 and 7.4 years) (12).

The effectiveness of the Tooth Coronal Index (TCI) in age estimation can vary significantly depending on several important factors, such as the demographic characteristics of the population analyzed, the type of teeth used in the calculation, and the methods applied in the data collection process, such as the use of panoramic radiographs compared to periapical radiographs. Each of these factors can affect the accuracy of the age estimation results obtained through the TCI method. For example, differences in tooth structure or rates of tooth development between individuals of different ethnic groups or ages can cause variations in the estimation results. Additionally, the choice of radiograph type plays a crucial role in accurately measuring and assessing TCI, as different radiographic techniques can produce varying images of tooth structure. This suggests that while some populations or groups may show no significant difference between dental age and chronological age, other groups may show considerable differences. Therefore, it is essential to consider the factors that may impact the accuracy of each TCI application, taking into account the characteristics of the population being studied (7,13,14).

Factors that can affect the results of dental age measurements using the Tooth Coronal Index (TCI) method are pretty diverse, one of which is the weakness of panoramic radiography. Panoramic radiography often produces images with lower detailed quality, which can lead to inaccurate measurements of coronal height and pulp cavity height, potentially affecting the accuracy of the measurement. Additionally, this technique tends to produce enlargement and distortion of the image, which can lead to errors in measuring the coronal size of the tooth and impact age estimation. To minimize these estimation errors, it is essential to employ radiographic techniques that reduce distortion and provide better image quality, such as periapical radiographs or the latest high-resolution radiographic technology. Additionally, the difficulty in determining the measurement reference point is a factor that affects the accuracy of TCI (7,15). Measurement of TCI values is highly dependent on selecting the correct reference point in the anatomical planeof the teeth. Inaccurate or inconsistent reference points can lead to variations in ageestimation results, so accurate measurements require expertise and a thorough understanding of dental anatomy and the radiographic techniques employed. Precise measurements require skills in determining reference points on radiographic images, which is often a challenge for practitioners who perform dental age estimation (13,14).

Variations in tooth size, such as the selection of specific teeth for analysis (e.g., first molars or second premolars) and the measurement technique employed (e.g., manual or software-assisted), can lead to differences in TCI results (13). Differences in the pattern of secondary dentin apposition levels and the angle of acquisition between the film and the X-ray beam are amongf the factors that can affect measurement results in the Tooth Coronal Index (TCI) method. These factors can cause variations in the radiographic image that ultimately impact the accuracy of dental age estimation. One crucial factor that affects image quality is the patient's position during image acquisition. Incorrect positioning can distort the image, leading to inaccurate measurements (16–18).

In addition, the quality of panoramic radiographic images can also decrease due to several other technical factors, such as errors in beam exposure, incorrect radiation dose, and inaccuracies in determining the image angle. Errors in this case can cause the resulting image to have significant distortions, which ultimately affect the results of the age estimation obtained. Difficulties in positioning the patient correctly often result in substantial discrepancies between chronological age and biological age on panoramic radiographic images. When the patient is not positioned correctly, the resulting images tend to be highly distorted, which can result in a

Based on the results of the research that has been conducted, it can be concluded that TCI showed minimal predictive value for chronological age, and no significant difference was observed between chronological age and dental age. These findings suggest that TCI alone is insufficient for accurate age estimation and should be complemented with additional indicators in this population.

Declaration of Interest

None

Author Contributions

AS: conceptualization, formal analysis, methodology, writing original draft, review & editing, supervision; APZ: data curation, writing original draft, formal analysis; NSR: writing original draft, review & editing; NR: review & editing.

Statement on the use of artificial intelligence in manuscript preparation

The authors acknowledge the use of artificial intelligence (AI) tools in the preparation of this manuscript to assist in language editing, grammar correction, and refining sentence structure to improve clarity and readability. The intellectual content, study design, data interpretation, and conclusions presented in this manuscript are solely the work of the authors. The authors performed all critical thinking, scientific analysis, and decision making, and no generative AI was used for data generation, analysis, or drawing scientific conclusions.

Table 1. Intraclass Correlation.

	Intraclass Correlation	Lower Bound	Upper Bound	F Value	df1	df2	Sig
Single Measures	0.931	0.900	0.953	28.120	99	99	0.000
Average Measures	0.964	0.947	0.976	28.120	99	99	0.000

Table 2. Normality test.

	Statistic	df	Sig.
Chronological Age	0.096	100	0.025
Dental Age	0.078	100	0.143

Table 3. Homogenity Test.

	Levene Statistic	df1	df2	Sig.
Chronological Age	0.306	1	98	0.581
Dental Age	2.075	1	98	0.153

Table 4. Pair t-test.

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Dental Age (DA)	33,2270	100	0,58442	0,05844
	Cronologis Age (CA)	33,2227	100	5,81503	0,58150
Pair 2	DA Male	33,3000	50	0,55754	0,07885
	CA Male	33,7385	50	5,84213	0,82620
Pair 3	DA Female	33,1540	50	0,60689	0,08583
	DA Female	32,7068	50	5,80050	0,82031

Table 5. Analysis of difference between mean age, MAE based on Gender.

Gender	n	mean SD	mean age	MAE (yr)	Trend	P-value	R^2
Total Sample	100	33.22 ± 5,81	0,0043	4,9220	O	0,994	0.010
Male	50	33,73 ± 5,84	-0,4385	4,9493	U	0,501	0.009
Female	50	32,71 ± 5,80	0,4472	4,8948	O	0.064	0,070

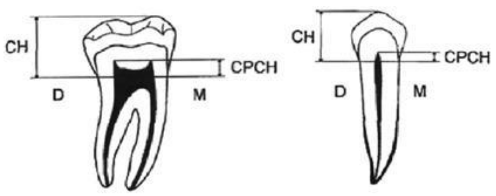

Figure 1. Tooth Coronal Index (D=distal, M=mesial) (1).

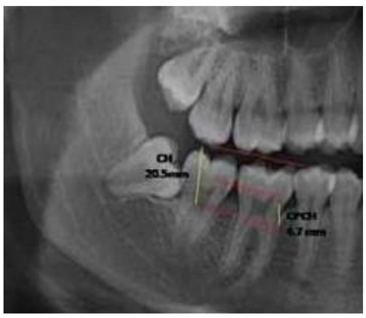

Figure 2. Calculation of CH and CPCH values in molar mandibular (1).

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