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COMPARISON OF THE ACCURACY OF THE TOOTH CORONAL INDEX BENINDRA AND THE KVAAL METHOD FOR ESTIMATING ADULT AGE USING PANORAMIC RADIOGRAPHS

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ABSTRACT

Background: Dental age estimation plays an important role in forensic identification and legal assessments of living individuals. In adults, estimation commonly relies on age-related secondary dentin deposition, which reduces pulp cavity dimensions. The Tooth Coronal Index (TCI) Benindra and Kvaal methods assess these changes using different radiographic measurements. This study compared the accuracy of these methods for adult dental age estimation using digital panoramic radiographs.

Purpose: This study aimed to analyze the accuracy of the TCI Benindra and Kvaal methods for adult age estimation using panoramic radiographs.

Methods: This cross-sectional design used 100 panoramic radiographs. We analyzed the data using the Statistical Package for the Social Sciences software, including a Wilcoxon signed-rank test, and assessed accuracy using mean absolute error (MAE).

Results: TCI Benindra significantly underestimated age across all three teeth, with mean differences of −4.59 ± 5.35, −7.32 ± 6.18, and −8.24 ± 6.46 years, respectively (all $p < 0.001$). Kvaal also underestimated age for the maxillary second premolar (−2.39 ± 7.89 years; $p = 0.003$), but overestimated age for the mandibular canine (8.94 ± 6.94 years) and first premolar (3.45 ± 8.95 years) (both $p < 0.001$). TCI Benindra demonstrated significantly lower MAE than Kvaal for the maxillary second premolar (5.29 vs. 6.70 years; $p = 0.008$) and mandibular canine (7.47 vs. 9.94 years; $p = 0.014$). For the mandibular first premolar, Kvaal showed a lower MAE, although the difference was not statistically significant.
Conclusion: The accuracy of adult dental age estimation varied by method and tooth examined. TCI Benindra

performed better for the maxillary second premolar and mandibular canine, whereas Kvaal showed a numerical advantage for the mandibular first premolar. Neither method performed consistently better across all tooth types.

Keywords: Dental Age Estimation; Legal Identity; Kvaal Method; TCI Benindra Method; Panoramic Radiograph

1 INTRODUCTION

Age estimation is a crucial component in investigating unidentified victims. In addition to establishing a personal identity, the identification process also applies to living individuals for criminal and civil legal purposes.[1] The results of age estimation are used to determine an individual's legal status, particularly in distinguishing whether a person is classified as a minor or an adult, which is associated with differences in legal procedures and judicial processes.[2]

Age estimation compares biological age with chronological age. Chronological age refers to the numerical age calculated from the birth date. In contrast, biological age is assessed based on growth and developmental changes in body tissues, including skeletal and dental structures.[3] Dental age is considered more reliable than skeletal age because nutritional, hormonal, environmental factors, and systemic diseases influence tooth mineralization relatively less.[4] In adults, dental age estimation is primarily based on post-formation changes of the teeth, particularly the deposition of secondary dentin, which leads to progressive narrowing of the pulp chamber with increasing age.[5,6]

Radiographic methods are widely used to estimate dental age because they are non-invasive and efficient, with panoramic radiography among the most commonly used imaging modalities.[1,7,8] Panoramic radiographs, along with supporting anatomical structures, allow comprehensive visualization of both maxillary and mandibular dentition within a single image, along with supporting anatomical structures.[8]

Various radiograph-based methods for adult dental age estimation have been developed, including the Kvaal method and the Tooth Coronal Index (TCI) Benindra, both of which use the reduction of pulp space resulting from secondary dentin deposition, albeit with different measurement techniques. Previous studies have demonstrated variability in the accuracy of these methods, influenced by tooth type, age group, and population characteristics. Therefore, this study aimed to compare the accuracy of the TCI Benindra and Kvaal methods for estimating adult age using panoramic radiographs.

2 MATERIALS AND METHODS

This study was an observational analysis of panoramic radiographs from 100 patients aged 26–45 years at the Radiology Department of Airlangga Dental Hospital, Surabaya, in 2024-2025. The sample was selected using purposive sampling based on key inclusion criteria: presence of maxillary second premolars, mandibular canines, and mandibular first premolars; presence of all parts of the studied teeth on the panoramic radiograph; and absence of missing teeth in the studied region. Key exclusion criteria were radiographs with pathological features of the teeth and surrounding tissues, patients using orthodontic or denture appliances, and developmental anomalies. Ethics approval for this study was obtained from the Ethics Committee of the Indonesian Dental Hospital Airlangga University Health Research (36/UN3.9.3/Etik/PT/2025). A single observer checked all sample measurements twice at 1-week intervals.

We evaluated all digital panoramic radiographs using the Benindra technique and the Kvaal method. Age estimation analysis using the TCI Benindra method was performed by measuring the CH and CPCH (Figure 1). The TCI value was calculated using the following formula: TCI = CPCH × (100/CH). Subsequently, the calculated TCI values were substituted into Benindra's regression equation to estimate age, expressed as Predicted age = 29.16 − (0.4 × TCI).[9]

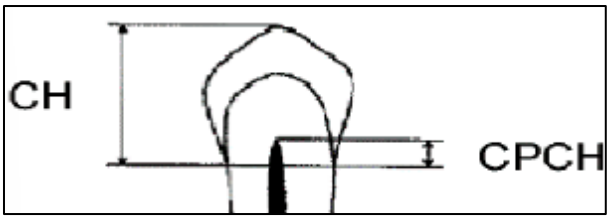


Figure 1: Illustration of TCI Benindra measurement method

Age estimation analysis using the Kvaal method was performed by measuring the maximum tooth length, pulp length, and root length on the mesial side, pulp width at level *a* (CEJ), level *c* (mid-root level), and level *b* (located between levels *a* and *c*), and root width at levels *a*, *b*, and *c*. The following ratios were calculated: root length/tooth length (T), pulp length/tooth length (R), pulp length/root length (P), pulp width/root width at level *a* (A), pulp width/root width

at level *b* (B), and pulp width/root width at level *c* (C). The mean value of all ratios (M), the mean of width ratios at levels *b* and *c* (W), the mean of length ratios P and R (L), and the difference between W and L (W − L) were also determined (Figure 2).[10]

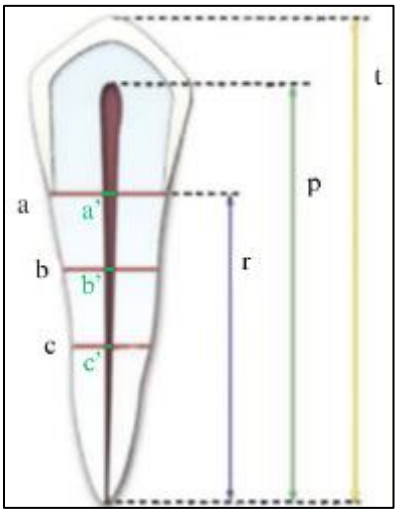


Figure 2: Illustration of the Kvaal measurement method.

3 RESULTS

The intraclass correlation coefficient test was used to measure the intra-examiner reliability. The results showed good to excellent agreement, with ICC values ranging from 0.886 to 0.978, indicating highly reliable and replicable measurements. With a *p*-value less than 0.05, the Kolmogorov-Smirnov test indicated non-normality, so we used non-parametric tests for further analyses. We used the Wilcoxon signed-rank test to examine differences in CA and EDA between the TCI Benindra and Kvaal methods.

Table 1 shows that the TCI Benindra method revealed statistically significant differences between CA and EDA for all examined teeth ($p < 0.001$). The mean age differences between CA and EDA were -4,59 ± 5,35 years for the maxillary second premolar, -7,32 ± 6,18 years for the mandibular canine, and -8,24 ± 6,46 years for the mandibular first premolar, respectively, indicating a consistent underestimation of age.

Similarly, the Kvaal method revealed significant differences between CA and EDA for all examined teeth. The mean difference for the maxillary second premolar was -2,39 ± 7,89 years, indicating underestimation, whereas the mandibular canine and mandibular first premolar demonstrated overestimation with mean differences of 8,94 ± 6,94 years and 3,45 ± 8,95 years (Table 2).

Table 3 compares the mean absolute error (MAE) between the TCI Benindra and Kvaal methods. MAE differed significantly for the maxillary second premolar ($p = 0,008$) and mandibular canine ($p = 0,014$), with the TCI Benindra method showing higher accuracy. In contrast, no significant difference in MAE was found for the mandibular first premolar ($p = 0,695$), whereas the Kvaal method demonstrated slightly better accuracy.

Table 1: Statistical analysis of the CA and EDA TCI Benindra

Tooth	CA (X ± SD)	EDA, TCI, Benindra (X ± SD)	Age Difference (X ± SD)	*P-Value*	Remarks
15/25	31,79 ± 5,19	27,18 ± 2,87	-4,59 ± 5,35	< 0,001	Underestimated
33/43		24,45 ± 3,95	-7,32 ± 6,18	< 0,001	Underestimated
34/44		23,53 ± 3,57	-8,24 ± 6,46	< 0,001	Underestimated

Table 2: Statistical analysis of the CA and EDA Kvaal

Tooth	CA (X ± SD)	EDA, TCI, Benindra (X ± SD)	Age Difference (X ± SD)	*P-Value*	Remarks
15/25	31,79 ± 5,19	29,39 ± 7,26	-2,39 ± 7,89	0,003	Underestimated
33/43		40,72 ± 5,42	8,94 ± 6,94	< 0,001	Overestimated
34/44		35,23 ± 9,01	3,45 ± 8,95	< 0,001	Overestimated

Table 3: Statistical analysis of the MAE TCI Benindra and the MAE Kvaal

Tooth	MAE TCI Benindra (year)	MAE Kvaal (year)	*P-Value*	Remarks
15/25	5,29	6,70	0,008	Significant
33/43	7,47	9,94	0,014	Significant
34/44	8,41	7,80	0,695	Non-Significant

4 DISCUSSION

This study evaluated the accuracy of the TCI Benindra and Kvaal methods for adult age estimation using panoramic radiographs. The TCI Benindra method uses the mandibular first premolar because posterior teeth provide clearer pulp visualization on panoramic images, enabling more reliable pulp measurements; anterior teeth were excluded because their pulp margins are indistinct.[11,12] In contrast, the Kvaal method uses selected maxillary and mandibular single-rooted teeth that show strong correlations between pulp–root ratios and chronological age, as it is unsuitable for multirooted teeth because ratio values are inconsistent.[9,13] Accordingly, the study selected maxillary second premolars, mandibular first premolars, and mandibular canines as samples.

The TCI Benindra method consistently produced underestimation in maxillary second premolars, mandibular canines, and mandibular first premolars. This finding aligns with the previous studies by Sharma et al.[14] and Woroprobosari et al.[12], which showed that secondary dentin deposition does not progress linearly with age and varies among different tooth types. However, a study in the adolescent Banjar population by Yulianti et al.[1] found an overestimation of age. Among the evaluated teeth, the maxillary second premolar showed the highest accuracy using the TCI Benindra method, indicating that coronal pulp height reduction in this tooth may better reflect age-related changes compared to other teeth, as also suggested by Drusini et al.[11] and Nagi et al.[15]

Sharma et al.[14] reported that age estimation using the TCI Benindra method underestimated age in the Indian population aged 20–30 years. This also aligns with a study by Woroprobosari et al.[12], who reported underestimation in 30.4% of their total sample when comparing estimated age with chronological age. In contrast, Yulianti et al.[1] reported an overestimation in an adolescent Banjar population, with a mean age difference of 0.4 years.

The Kvaal method showed underestimation in the maxillary second premolars but overestimation in the mandibular canines and first premolars. Previous studies by Li et al.[16] and Ramli et al.[17] reported systematic overestimation when applying the Kvaal method outside the original reference population. Li et al.[16] reported age overestimation in a Malaysian adult population, with age differences ranging from +9 to +11 years relative to chronological age. Similarly, Ramli et al.[17] found an overestimation in a Chinese population, with a mean age difference of 8.6 ± 11.8 years. These discrepancies may reflect differences in root morphology, pulp chamber configuration, and the rate of secondary dentin apposition, all of which influence the pulp–tooth ratios used in the Kvaal formula.[9]

Accuracy assessment using mean absolute error revealed significant differences between the two methods. This agrees with previous research by Farahyati et al.[9], who reported significant differences in age estimation accuracy between the TCI Benindra and Kvaal methods. The TCI Benindra method demonstrated higher accuracy in maxillary second premolars and mandibular canines than the Kvaal method. These findings highlight how methodological principles affect estimation outcomes. The TCI Benindra method relies exclusively on coronal pulp height measurements, making it sensitive to variations in crown morphology. In contrast, the Kvaal method incorporates multiple linear and width ratios of the tooth and pulp, which may increase susceptibility to anatomical variability.[9,10]

Population-related factors, such as genetic background, nutrition, lifestyle, and oral habits, may further influence secondary dentin deposition and pulp chamber reduction, thereby affecting estimation accuracy.[16,18] Bad habits, such as bruxism, can stimulate the natural protection of secondary dentin deposition, and the thickness of secondary dentin deposition may vary in individuals with such habits.[12] Additionally, the use of panoramic radiographs may introduce distortion, magnification errors, and reduced image resolution compared to periapical radiographs, particularly in posterior regions, which can affect measurement precision.[19,20]

5 CONCLUSION

In conclusion, both the TCI Benindra and Kvaal methods can be considered applicable for adult age estimation when appropriate tooth selection is considered in the calculation. The TCI Benindra method appears to be more reliable for maxillary second premolars and mandibular canines, whereas the Kvaal method performs better in mandibular first premolars. These findings emphasize the importance of applying dental age estimation methods based on population and tooth. To improve the accuracy and reliability of adult dental age estimation in forensic practice, future studies should include larger sample sizes, incorporate additional influencing variables, and explore alternative imaging modalities.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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