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Comparative assessment of the accuracy of Cameriere's third molar maturation index method among three different radiographic techniques in a Turkish population

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ABSTRACT

Age estimation of living or deceased individuals can be done for ethical, social and legal purposes and is of paramount importance in forensic medicine. Teeth play a crucial role in age estimation. Third molars can be used for dental age estimation as they are the only teeth still developing at the legal age of 18 years. The aim of this study was to compare the accuracy of Cameriere's third molar maturation index method when used with panoramic, periapical and cone beam computed tomography imaging techniques and to test its applicability. The study sample included 101 panoramic radiographs, 101 periapical radiographs and 100 CBCT images from 302 individuals aged 14–24 years. Sensitivity, specificity and accuracy of Cameriere's third molar maturation index method were 71%, 97% and 83.1% for panoramic radiographs, 75%, 87.2% and 81.1% for periapical radiographs, and 61.9%, 100% and 72.7% for CBCT images, respectively. Although the cut-off value of 0.08 was applicable for both sexes, it provided more accurate results in males. Although all three imaging methods were acceptable, Cameriere's third molar maturation index method provided the most accurate results on panoramic images in the Turkish population studied.

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KEYWORDS
Age estimation; cut-off value; legal age; third molar maturity index

1. Introduction

Forensic age estimation is performed in the context of civil lawsuits, criminal investigations as well as for persons lacking any identification documentation and individuals who are incapable of expressing themselves. It is also necessary for clinical dentistry, anthropological and archaeological studies and in the event of a mass disaster[1,2]. The legal age of majority (also known as the age of maturity) of an individual is defined as the age at which a child becomes an adult and gains full legal capacity. This age threshold is accepted as 18 in most countries and Turkey[3].

Many radiological methods have been reported for dental and skeletal age estimation in the literature. The Study Group on Forensic Age Diagnostics (AGFAD) recommend physical examination and X-rays of the teeth and left hand for age estimation in living individuals[4]. Teeth play a key role in age estimation because of their hard structural features, long-term preservation of their morphology and their outstanding ability to

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resist mechanical, chemical and physical effects and time[5,6]. The last teeth to erupt and develop are the third molars. While the other permanent teeth complete their development up to the age of 14 years, the third molars continue to mature up to the age of 22 years[7,8]. Therefore, the development of the third molar tooth is a reliable biological indicator when estimating whether an individual has reached adulthood[1].

In young adults, age estimation methods are based on the analysis of morphological features of bones and tooth development. However, age estimation methods become less reliable with increased age. This is because the teeth have completed their development. Dental age estimation can be easily done up to the age of 14, when the teeth have completed their crown-root development. With the completion of the root development of the second molar tooth, it becomes difficult to determine dental age. Only the third molars continue to develop after this age. Therefore, the use of third molars becomes important in determining dental age after the age of 14 years[9–11]. Age estimation using third molars has been evaluated by many investigators, but consensus on the reliability of these teeth has not been reached[12]. This is due to the variability in the position, morphology, and development of third molars[9].

In 2008, Cameriere et al. developed a practical method to determine adult age using panoramic radiographs[13]. Their method relies on the relationship between age and third molar maturation index (I_{3M}). In this method, apical width and tooth length are measured and their ratio is calculated. A cut-off value of 0.08 was reported using this method and used to determine whether a person is under or over 18 years of age[13]. The validity of this cut-off value has been tested and demonstrated in diverse populations[14–20].

To the best of our knowledge, age estimation using the third molar index method has been performed only with panoramic radiographs. No study is available in the literature, which tested the performance of Cameriere's method in comparison to periapical and 3D radiographic imaging techniques.

The current study aimed to comparatively assess the applicability and accuracy of Cameriere's third molar maturation index method when used with panoramic, periapical and CBCT techniques.

2. Materials and methods

2.1. Samples

A total of 410 radiographs obtained from paediatric and adult patients from 14 to 24 years of age presenting to Faculty of Dentistry, Department of Dentomaxillofacial Radiology were examined. After excluding non-eligible images, 302 radiographs (panoramic and periapical radiographs (n = 101 each) and 100 CBCT images) were included in the study. These radiographs and images, each from different individuals, belonged to 166 females (55%) and 136 males (45%). Inclusion criteria were as follows: 14–24 years of age at the time of radiographic imaging, good quality radiographs, absence of a systemic disease and individuals with known chronological age. Patients of unknown age, absent third molars, malformed third molars, and a systemic disease affecting dental and skeletal development were excluded from the study. Sex, date radiograph taken and date of birth were recorded for each patient. Chronological age was calculated by subtracting the date of radiograph from the date of birth. The study protocol was approved by the Non-

Interventional Clinical Researches Ethics Board (approval no. 2020-02/02). This study was conducted in accordance with the ethical principles laid out in the Declaration of Helsinki (Finland).

2.2. Measurements

In this study, all panoramic radiographs were obtained using an Orthopantomograph OP200 D (Instrumentarium Digital Panoramic System, KaVo Dental, Tuusula, Finland) device, periapical radiographs using a Planmeca ProX (Planmeca Oy, Helsinki, Finland) device, and all CBCT images using a Planmeca Promax 3D Mid (Planmeca Oy, Helsinki, Finland) dental volumetric tomography device. Radiographs were taken by the same technician to ensure standardization. Panoramic radiographs were obtained using the automatic dose control (ADC) feature, which allows the device to deliver a personalized radiation dose. Periapical radiographs were taken at 0 and −5 degrees using the bisecting-angle technique at individually varying vertical angles and one of the irradiation parameters of 60 kVp, 7 mA, 0.125 sec or 63 kVp, 6 mA, 0.160 sec was preferred according to the age group of the patient and the lower molar tooth region. CBCT images were acquired at 90 kVp, 10 mA, 200 µm voxel size and 20.0 × 6.2 cm FOV. Measurements from third molar teeth were obtained on 3D CBCT images on which a bone algorithm programknown as maximum intensity projection (MIP) was applied. The MIP bone algorithm provides a 3D radiograph, which can be rotated in space to optimize the visualization of the long axis of the tooth and the degree of development of the crown and root[21].

In this study, left lower third molars were evaluated irrespective of the eruption status[13]. Measurements on the study radiographic images were obtained by the same person using the Image J (1.50n, National Institutes of Health, Bethesda, MD, USA) program, on a 1920 × 1080 resolution, 15.6-inch LED (Light-Emitting Diode) screen in a semi-lit room. I_{3M} was assessed in a similar way to the I_{3M} as described by Cameriere et al. for the first and second lower molars[22]. For the measurements, the apical width (distance between the inner sides of the apices) was recorded as A8 = (A81 + A82) and the tooth length as L8 (Figure 1). The third molar maturation index (I_{3M}) was calculated by dividing the sum of open apices with the tooth length (I_{3M} = A8/L8). In addition, I_{3M} = 0.0 was recorded if the root development of the third molar tooth was complete.

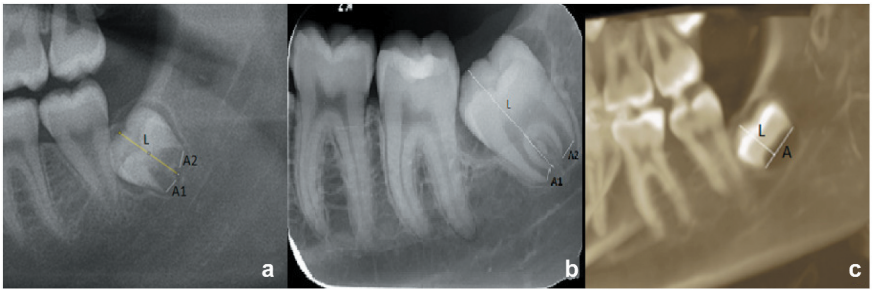

Figure 1. Example of measurement of A8 and L8 in the third molar on (a) Panoramic radiograph, (b) Periapical radiograph, (c) CBCT 3D MIP image.

Before the study, a dentomaxillofacial radiology resident and a paediatric dental resident, who were unaware of the identity, age and sex of the participants reviewed 25 randomly selected radiographs (25%) from each group at two-week intervals to determine the intra- and inter-observer agreement.

2.3. Statistical analysis and data management

The SPSS 22.0 for Windows (SPSS Inc., Chicago, IL) and MS Excel 2013 (Microsoft Office 2013, Microsoft, Redmond, WA) were used for statistical analysis and data management. Cohen's kappa coefficient was used to assess intra- and inter-observer agreement. The cut-off value was set at 0.08 and for each radiography technique. The sensitivity (i.e. the percentage of individuals 18 years of age or older with an $I_{3M} < 0.08$) and specificity (i.e. the percentage of individuals under 18 years of age with an $I_{3M} \geq 0.08$) of the test were calculated[13]. In addition, Receiver Operating Characteristic (ROC) curves were plotted for each radiography technique. Effectiveness of I_{3M} was evaluated using ROC curves. The area under the ROC curve (AUC) value indicates the accuracy of the test (i.e. how well test distinguishes the adults or minors). An AUC of 1 represents a perfect test, whereas an AUC of 0.5 represents a worthless test[16]. The significance level was set at 0.05 for all tests.

3. Results

The sex and age distribution of 166 females (55%) and 136 males (45%) are shown in Table 1. The Cohen kappa test, which was performed for the measurements on 25 randomly selected radiographs from each group (25%), revealed an excellent agreement, with an intra-observer agreement of 0.947 and an inter-observer agreement of 0.946 for panoramic radiographs. Intra-observer agreement and inter-observer agreement were 0.946 and 0.945 for periapical radiograph, respectively. For CBCT images, intra-observer agreement was 0.946 and inter-observer agreement was 0.944. The Cohen kappa test revealed an excellent agreement for all three radiograph techniques.

The mean chronological age and standard deviation for each third molar maturation index (I_{3M}) category were calculated from panoramic and periapical radiographs, and CBCT images in detail for females and males. For all three radiograph techniques, the mean age for both sexes varied across I_{3M} categories, and the difference was statistically

Table 1. Sample distribution according to sex and age.

Age (years)	Male	Female	Total
14	22	15	37
15	12	15	27
16	12	16	28
17	19	13	32
18	9	17	26
19	10	19	29
20	10	10	20
21	19	22	41
22	13	20	33
23	6	9	15
24	4	10	14
Total	136	166	302

Table 2. Number of individuals, mean and standard deviation (SD) of age distribution by sex for each I_{3M} category on panoramic radiographs.

	Males		Females		
I_{3M}	N	Mean ± SD	N	Mean ± SD	p**
[0–0.04)	16	21.12 ± 1.31	18	20.38 ± 1.71	0.174
[0.04–0.08)	0	-	5	22.20 ± 0.83	-
[0.08–0.3)	11	16.63 ± 1.28	11	18.18 ± 2.13	0.053
[0.3–0.5)	5	15.00 ± 0.70	7	17.14 ± 1.46	0.008*
[0.5–0.7)	4	14.50 ± 0.57	4	15.00 ± 0.81	0.356
[0.7–0.9)	6	15.66 ± 1.86	6	14.66 ± 0.81	0.268
[0.9–2)	6	14.16 ± 0.40	2	15.00 ± 1.41	0.556

Bolded significance at the level of <0.05%.
**Independent samples t-test.

Table 3. Number of individuals, mean and standard deviation (SD) of age distribution by sex for each I_{3M} category on periapical radiographs.

	Males		Females		
I_{3M}	N	Mean ± SD	N	Mean ± SD	p**
[0–0,04)	22	20.72 ± 1.93	20	20.90 ± 2.04	0.780
[0,04–0,08)	0	-	5	20.80 ± 2.16	-
[0,08–0,3)	11	17.09 ± 1.30	19	17.47 ± 1.54	0.494
[0,3–0,5)	6	16.00 ± 1.54	7	16.42 ± 1.71	0.648
[0,5–0,7)	1	14.00	3	15.33 ± 0.57	-
[0,7–0,9)	2	15.00 ± 1.41	2	14.00 ± 0.00	-
[0,9–2)	1	15.00	2	14.50 ± 0.70	-

**Independent samples t-test.

Table 4. Number of individuals, mean and standard deviation (SD) of age distribution by sex for each I_{3M} category on CBCT.

	Males		Females		
I_{3M}	N	Mean ± SD	N	Mean ± SD	p**
[0–0,04)	15	21.46 ± 1.88	22	22.00 ± 1.79	0.391
[0,04–0,08)	5	19.60 ± 1.51	2	20.00 ± 1.41	0.762
[0,08–0,3)	11	18.90 ± 1.75	17	19.88 ± 2.34	0.250
[0,3–0,5)	5	16.00 ± 2.82	4	16.50 ± 2.88	0.801
[0,5–0,7)	1	16.00	1	14.00	-
[0,7–0,9)	3	14.00 ± 0.00	1	14.00	-
[0,9–2)	5	15.20 ± 1.64	8	15.50 ± 1.51	0.742

**Independent samples t-test.

significant when I_{3M} was between 0.3 and 0.5 in panoramic radiographs ($p < 0.05$) (Table 2). For periapical radiographs and CBCT images, the difference in the mean age between the sexes was not statistically significant ($p > 0.05$) (Tables 3 and 4).

The reliability of the cut-off value of 0.08 suggested by Cameriere et al.[13] and the validity of I_{3M} were analysed separately for each radiography technique. The results are summarized in a contingency table. For each radiography technique, the numbers of individuals 18 years of age or older (true positive) and those younger than 18 (false positive) with an I_{3M} of <0.08 is shown in the first row, and the numbers of individuals younger than 18 (true negative) and those 18 years of age or older (false negative) with an I_{3M} of ≥0.08 are shown in the second row (Table 5).

Table 5. Contingency table describing discrimination performance of the test for each radiography technique.

Radiography Technique		Age (years) ≥18	Age (years) <18	Total
Panoramic	I_{3M} < 0.08	38[a]	1[b]	39
	I_{3M} ≥ 0.08	15[c]	47[d]	62
	Total	53	48	101
Periapical	I_{3M} < 0.08	41[a]	6[b]	47
	I_{3M} ≥ 0.08	13[c]	41[d]	54
	Total	54	47	101
CBCT	I_{3M} < 0.08	44[a]	0[b]	44
	I_{3M} ≥ 0.08	27[c]	29[d]	56
	Total	71	29	100

[a]True positive.
[b]False positive.
[c]False negative.
[d]True negative.

From the panoramic radiographs, 38 (71.6%) individuals older than 18 years of age were correctly classified at an I_{3M} of <0.08 (sensitivity); on the other hand, 47 (97.9%) individuals under 18 years of age were correctly classified at an I_{3M} of ≥0.08 (specificity), with a 95% confidence interval (Table 5).

On the periapical radiographs, age was correctly classified for 41 (75.9%) individuals older than 18 years of age when I_{3M} was <0.08 (sensitivity), whereas 41 (87.2%) individuals under 18 years of age were correctly classified when I_{3M} was ≥0.08 (specificity), with a 95% confidence interval (Table 5).

Using CBCT images, age was correctly classified for 44 (61.9%) individuals over 18 years of age at an I_{3M} of <0.08 (sensitivity), and for 29 (100%) individuals under 18 years of age at an I_{3M} of ≥0.08 (specificity), with a 95% confidence interval (Table 5).

The accuracy (area under the ROC curve) was calculated for panoramic and periapical radiographs, and CBCT images. Accuracy values were 83.1%, 81.1%, and 72.7%, respectively (Figure 2).

The sensitivity, specificity and accuracy of the I_{3M} method for each radiography technique and by sex are shown in Table 6. On panoramic and periapical radiographs and CBCT images, sensitivity, specificity and accuracy of the method were generally higher for males compared to females. Specificity on CBCT images was 100% for both sexes.

4. Discussion

Cameriere et al.[13] developed a practical method for the assessment of adult age in 2008 based on the relationship between age and the measurement of the open apices of the third molar, i.e. the third molar maturation index (I_{3M}). As a result of their study on panoramic radiographs, a cut-off value of 0.08 was reported, with 70% sensitivity and 98% specificity. In addition, the percentage of correctly classified individuals was 83%. Over time, this method has been applied to different populations using panoramic radiographs, and it has been widely agreed that the third molar index (I_{3M}) should be used as a predictor for estimating the age of majority[14–20]. Consistently, the present study

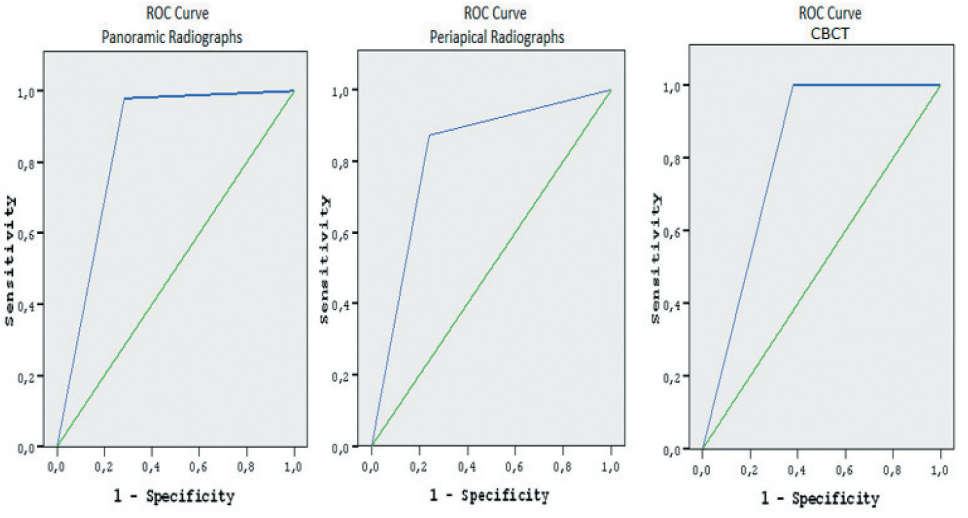

Figure 2. ROC curves indicating the sensitivity, specificity and accuracy of the I_{3M} index for age estimation among radiographic techniques. The points on each curve correspond to the sensitivity and specificity associated to the I_{3M} cut offs related to each curve. The value of area under the ROC curves indicates the accuracy of the test.

Table 6. Description of the accuracy of the I_{3M} index and other parameters for age estimation by each radiography technique and sex.

Radiography Technique	Population	Sensitivity	Specificity	Accuracy
Panoramic	Female	66,6%	95%	77,3%
	Male	80%	100%	91,6%
	Total	71,6%	97,9%	83,1%
Periapical	Female	63,6%	84,6%	72,8%
	Male	90,9%	90,4%	90,6%
	Total	75,9%	87,2%	81,1%
CBCT	Female	57,1%	100%	67,2%
	Male	68,9%	100%	80%
	Total	61,9%	100%	72,7%

showed an accuracy of over 80% for panoramic radiographs, with similar sensitivity and specificity values compared to Cameriere's original study (70% and 98%, respectively) conducted in the Italian population.

To the best of our knowledge, studies on Cameriere's third molar maturation index method have only been performed on panoramic radiographs. This study is the first in the literature to evaluate the accuracy of I_{3M} to distinguish between adults and minors using three different imaging techniques.

In this study, sensitivity values of 66.6% and 80% found using panoramic radiographs in females and males, respectively, were lower than those reported for some populations (Chinese 77%, 87%; Colombian 95%, 91%; French 74%, 92%; Albanian 75%, 94%; Australian 90%, 90%)[16,23–26] and higher than those of Saudi and Indian populations (Saudi 51.3%, 52.3%, and Indian 66%, 74.7%)[17,27].

However, the test showed specificity values of 95% and 100% in females and males, respectively, which were higher than those of other populations (Indian 79%, 83%; Colombian 93%, 90%; French 88%, 88%; Australian 87%, 85%)[23,24,26,27]. Specificity in females was lower compared to those reported for Chinese (98%), Saudi (97%) and Albanian (96%) female populations[16,17,25].

A previous study on panoramic radiographs of 293 individuals in the Turkish population has reported lower sensitivity (85% and 94%, respectively) and specificity (100%, 100%, respectively) in females and males[20].

We think that genetic differences among populations and subgroups studied and different imaging algorithms used in panoramic devices may have accounted for all these differences.

In addition to the studies reporting that the test has lower accuracy in females than in males[14,16,17,20,28–30], there are also studies that found a higher accuracy in females[13,23]. In the present study, the accuracy of all three radiography techniques was lower for female compared to males.

A cut-off value of 0.08 can successfully distinguish individuals under the age of 18 among both males and females; however, it can produce a significantly high rate of false negativity in females. In males, the mineralization of the third molars is faster than in females[31]. The reason for the lower sensitivity in females than in males may be delayed root development of the third molars. This sex-related difference in mineralization of third molars may have affected the results of our study. Therefore, even when the same cut-off value is used, women older than 18 years of age may be incorrectly classified as children, due to ongoing root development. We suggest that setting a different cut-off value for females may perhaps improve the success of the method in populations with significant sexual dimorphism of third molars[1].

Since Cameriere's third molar maturation index method has not been evaluated on CBCT images previously in the literature, direct comparisons of CBCT results could not be made. However, although the accuracy of CBCT was lower than other imaging methods, it was still at an applicable level. Again, in estimating whether an individual was under 18 years of age, CBCT was superior with 100% specificity. In other words, incorrect classification of an adolescent individual as an adult did not occur with CBCT compared to other two imaging techniques. However, it was less successful than other imaging methods in distinguishing individuals older than 18 years of age. We consider that low contrast resolution of CBCT images may have led to misleading results on apex width measurements. Also, as reported in the literature, MIP images are obtained by evaluating each voxel value and defining only the highest value as the imaging value, and voxel intensities below the threshold value are excluded[32]. This may have affected the accuracy of the measurements in our study.

The results obtained from periapical radiographs could not be compared because there is no literature data using a similar method. However, periapical radiographs showed lower accuracy than panoramic radiographs and higher accuracy than CBCT.

Determining the legal age is important for holding individuals accountable for their actions or protecting children's rights. The consequences of a criminal violation can greatly affect an individual's life. Therefore, it is crucial to decide whether an individual is of legal age[18]. The major problem with age estimation methods is that they cannot safeguard children's rights. As a result of any mistake, describing an adolescent as an adult

(false positive) may cause the individual to receive a severe punishment, or describing an adult as an adolescent (false negative) may cause the individual to receive a lighter punishment. The latter is more ethically acceptable than the former[33]. Age estimation methods should minimize errors, be simple and easily applicable[34,35]. At the same time, incorrect classification of an adolescent as being an adult, which is considered as a grave mistake in age estimation that must be avoided due to ethical reasons, occurred at the highest rate with periapical radiographs. In this study, bisecting angle technique was preferred because it is more practical. We suggest that using this method on periapical radiographs obtained with the parallel technique, which is a less practical technique but offers an advantage of minimal distortion, may provide more reliable results.

5. Conclusion

Although Cameriere's third molar maturation index technique was found to be applicable in the Turkish population in distinguishing individuals under or over the age of 18 years with all three imaging techniques, the method provided more reliable results with panoramic imaging and in males. However, we think that this method should also be evaluated on periapical radiographs using the parallel technique.

Disclosure statement

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

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