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Reliability of mathematical regression models for age estimation in the mixed dentition stage for Egyptian children

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Abstract

Background The purpose of this study was to evaluate the accuracy of established mathematical regression models for estimating the age of Egyptian children, develop new models that would better match this population and to evaluate the validity and reliability of these new models.

Results One thousand one hundred fifteen children ranging in age between 6–14 years participated in the study. Group I consisted of 1000 children; 513 (51.3%) children were of the age group 6–< 9 years and 487 (48.7%) children were 9–14 years. Male children were 484 (48.4%) while female children were 516 (51.6%). Group II consisted of 115 children; 84 (73%) children were of the age group 6–< 9 years and 31 (27%) children were 9–14 years. Male children were 58 (50.4%) while Female children were 57 (49.6%). Foti regression models showed poor agreement of Intraclass Correlation Coefficient (ICC) with chronological age of children in the mixed dentition stage. The new regression models for estimating dental age showed ICC of more than 0.7 with chronological age suggesting better accuracy in age estimation than Foti models.

Conclusions The newly formulated regression models are reliable for estimating the age of Egyptian children during the mixed dentition stage. A good agreement was found between the estimated age obtained from the first two models and the chronological age. However, the third model had the least agreement, suggesting that age estimation may be more accurate using only the first two models.

Keywords Age estimation, Dental age, Forensic, Eruption, Regression models, Mixed dentition

Background

Age determination plays a key role in forensic and clinical dentistry. A reliable estimation of a child's age is always required for legal certainty or insurance issues (Singh and Pathak 2013). The identification of unknown dead bodies, as well as living children with unknown identity using age assessment, is required. In courts of law, the lack of documentation of a minor's age concerned with murders, criminal acts, refugees' requests, and immigrants' credentials could halt procedures of identification. Moreover, in forensics and during catastrophic events, the estimation of a child's age could become difficult with a reasonable degree of error (Gupta et al. 2007). Through forensic investigations, identification is primarily done by fingerprint, DNA, and dental examination. Secondary identification is achieved through age, race, sex, and skin color. Age assessment can be of great benefit for both pediatric dentists and orthodontists during their treatment planning since the management of developing occlusion in relation to bone growth is associated with age (Asab et al. 2011). Therefore, age as a reference is considered of great significance globally. Several different age

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estimation methods have been developed through the years to estimate age such as tooth development, cranial suture closure and epiphyseal-diaphyseal union (Menezes et al. 2011). However, dental development assessment has been widely used for age estimation as a non-invasive method (Ritz-Timme et al. 2000) although it is influenced by genetics, ancestry, and sex (Kırzıoğlu and Ceyhan 2012). Individuals of the same ancestral/racial population have similar patterns of dental development. This means that among different populations, differences in the timing and rate of dental development are normally expected (Blenkin and Evans 2010).

Dental age assessment can be accomplished through biochemical, histological, morphological, radiographical, and visual methods. All these methods involve evaluating the exact time and sequence of all defined growth stages of teeth development. They may also evaluate any modifications in this sequence due to genetic differences (Reppien et al. 2006). Biochemical methods use gravimetric methods to determine foetal age by weighing of mineralized tissue in the primary anterior teeth (Stack 1964). Histological methods require the preparation of tissues for microscopic examination and assess prenatal dental maturity by dissecting and staining fetal tooth germs with alizarin. (Dangerfield 2001). Morphological methods of dental age estimation require the microscopic analysis of extracted teeth (Priyadarshini et al. 2015).

Radiographic methods are based on the time of emergence of the tooth through the gingiva and on dental maturity stages. They assess the amount of tooth mineralization from the start of tooth calcification until it has a closed apex using various radiographic images as periapical, panoramic or cone beam radiographs. Several methods and approaches have been developed, such as the London atlas published by AlQahtani (AlQahtani et al. 2010) which utilizes standard age charts to interpret radiographs of tooth development. Another variety of radiographic methods are scoring systems for different tooth development stages. They interpret tooth development presented on panoramic radiographs, which is then converted to scores that are evaluated with statistical analysis using techniques such as Nolla, Cameriere, Willems and Demirjian (Panchbhai 2011). Unfortunately, all radiographic methods come with the risk of increased exposure to radiation for individuals (Baccetti et al. 2005). Clinical visual methods can assess dental age as they are related to the presence of teeth in the oral cavity. Since the time of eruption for each tooth is relatively constant, it can be easily related to age. The eruption of teeth is one of the processes that can be easily noted. Consequently, the assessment of a child's age by examining his teeth is one of the accepted methods of age estimation (Kumar and Sridhar 1990). Clinical methods of age assessment have been proven to be as good as radiographic methods (Kromeyer and Wurschi 1996). Additionally, chronological age can be estimated by the sequence of eruption rather than by using body weight or height (Żądzińska 2002). Moreover, clinical methods would be of utmost importance in regions where facilities for radiography are unavailable.

Foti et al. (Foti et al. 2003) examined age estimation using linear regression in both living and deceased children. They developed regression models based on the number of erupted teeth and teeth germs as revealed by examination and through radiographs. These models were useful in age estimation up to 20 years of age. Unquestionably, these regression models proved to be easier to use and yielded more accurate results. However, the sample used to derive these regression models was validated on the French population. Different populations may respond differently to the same method as growth may occur in diverse ways. Different age estimation methods have a wide range of age determination; thus, more accurate and precise methods are still needed. Using mathematical regression models would allow the integration of these equations into a software application, enabling any personnel, not necessarily a dentist to have prompt information about a child's age. Moreover, the diversity of evolving new techniques and technologies necessitates the implementation of a more applicable and valid method to identify dental age just by detecting the erupted teeth in the oral cavity. However, to the best of our knowledge, no study has yet been conducted to assess the accuracy of the mathematical regression models developed by Foti et al. in determining chronological age among Egyptian children. Therefore, the purpose of this study was first to assess the accuracy of Foti regression models for estimating the age of Egyptian children during the stage of mixed dentition and second to establish new age estimation regression models and evaluate their validity and reliability for estimating the age of a sample of Egyptian male and female children during the mixed dentition. The null hypothesis was that Foti regression models is not an accurate method in estimating the age of Egyptian children during the mixed dentition stage.

Methods

Study design, setting and ethical consideration

This is a cross sectional study. It was approved by the Research Ethics Committee, Pharos University in Alexandria, Egypt (#PUA02202208283039) and was accomplished with adherence to the tenets of the Declaration of Helsinki 1964 and its later amendments. Participating children were recruited from 4 preparatory and 4 elementary schools in 4 different districts of Alexandria, Egypt during the period December 2020 till January 2022 during semesters. Consent forms were sent by the schools to the parents or legal guardians, with explanation of the benefits and the aim of procedure with assurance of maintaining records confidentiality. Their signed approval was imperative to include their child in the study. Likewise, at the time of examination, its purpose was explained to each child before proceeding.

Sample size estimation

Sample size estimation was based on 90% confidence level with significant level of 0.05 according to the following equation:

$$n = \frac{2\left(Z_a + Z_{1-\beta}\right)2\sigma^2}{\Delta^2}$$

where n is the required sample size. For Zα, Z is a constant set by convention according to the accepted α error. For $Z_{1\text{-}\beta}$, Z is a constant set by convention according to power of the study. σ is the standard deviation and Δ is the difference in effect of two interventions. The total sample size required was one thousand one hundred and fifteen children.

Eligibility

Children recruited for the study met the following inclusion criteria: aged between 6 -14 years; male or female; native Egyptians, having at least one erupted permanent tooth. Any child with underlying systemic, genetic, endocrine, or nutritional diseases or with a history of early loss of teeth due to caries or trauma was excluded from the study.

Randomization and grouping

Each of the 8 schools was randomly selected from each district, with 2 from each, using a computer-generated list of random numbers using RAND and RANK functions in Excel (MS Office 365). A serial number was given to each assigned school with a total of one thousand one hundred and fifteen children. Grouping was randomly allocated at the end of all examinations using the same randomization technique. Group I consisted of one thousand children for the first phase, while Group II consisted of one hundred and fifteen children for the fourth phase.

Procedure

Sex, birth date, examination date and teeth present in the oral cavity were recorded for all children. Chronological age was calculated by subtracting the birth date from the examination date to give the exact age in decimals for ease in statistical comparisons. Data for all available parameters was recorded to include all primary and/or permanent teeth and/or molars that were in the oral cavity at the time of examination. An Excel sheet was designed to calculate the estimated age according to Foti regression models (Foti et al. 2003). The parameters of these regression models were entered into their location on the sheet, and an exact estimated age was readily available for each participant. Furthermore, all other parameters in the oral cavity, apart from those included in Foti regression models, were recorded in the same sheet at their designated locations. Afterwards, Children were divided into two groups and the study was conducted on four consecutive phases.

In the first phase, the accuracy of the established regression models by Foti et al. (Foti et al. 2003) was evaluated on group I (1000 children). This group consisted of 484 (48.4%) male and 516 (51.6%) female children. The age of each child was estimated using these models and then compared to their chronologic age and sex. For further categorization, children were divided into two age groups: one group whose age ranged from 6 to less than 9 years and another group whose age was equal to or more than 9 to 14 years of age. Foti regression models are listed in Fig. 1. (Fig. 1).

In the second phase, linear regression analysis was performed to detect the most related parameters in estimating age in Egyptian population; whether the ones within Foti regression models or any other parameter.

In the third phase, new regression equations adapted to Egyptian population were developed. They were named as follows: Equation for both jaws: EGY I, equation for the upper jaw: EGY II, and equation for the lower jaw: EGY III.

In the fourth phase, group II consisted of 115 children: 58 (50.4%) males and 57 (49.6%) females. The validation and reliability of the newly developed regression equations were compared with children's chronological age, with the same age ranges specified earlier and with sex.

Study outcomes

The outcomes of the study included:

i. Assessing the accuracy of established mathematical regression models (Foti regression models) for age estimation on Egyptian children.
ii. Developing new regression models that are better suited to Egyptian population.
iii. Evaluating the reliability of the new models.

MODEL NO 1 (FOTI 1)	based on all the teeth present in the oral cavity at the time of examination	ESTIMATED AGE = 13.652 - (0.514 x number. of deciduous. upper incisors) - (0.236 x number of deciduous. upper molars) + (0.314 x number of permanent Upper canines) - (1.748 x number of permanent Upper 1st molars) + (1.012 x number of permanent Upper 2nd molars) + (0.944 x number of upper 3rd molars) + (0.252 x number of lower premolars) + (0.285 x number of permanent Lower 2nd molars) + (1.537 x number of lower 3rd molars)
MODEL NO 2 (FOTI 2)	regression model based on teeth present in the upper jaw	ESTIMATED AGE = 13.704 - (0.567 x number of deciduous upper incisors) - (0.367 x number of deciduous upper molars) + (0.530 x number of permanent Upper canines) - (1.449 x number of permanent Upper 1st molars) + (1.359 x number of permanent Upper 2nd molars) + (2.041 x number of erupted 3rd molars)
MODEL NO 3 (FOTI 3)	regression model based on teeth present in the lower jaw	ESTIMATED AGE = 9.726 - (0.571 x number of deciduous lower incisors) - (0.378 x number of permanent Lower canines) + (0.579 x number of lower premolars) + (1.056 x number of permanent Lower 2nd molars) + (2.236 x number of lower 3rd molars)

Fig. 1 Foti regression models

Table 1 Sample description

	Group I ($n=1000$) n (%)	Group II ($n=115$) n (%)
6—< 9 years	**513 (51.3%)**	**84 (73%)**
Male	250 (48.7%)	40 (48%)
Female	263 (51.3%)	44 (52%)
9—14 years	**487 (48.7%)**	**31 (27%)**
Male	234 (48%)	18 (58%)
Female	253 (52%)	13 (42%)

Outcome assessment

- The accuracy of Foti regression models for age estimation in Egyptian children was assessed using the Intraclass Correlation Coefficient (ICC) between all models and chronological age.
- New regression models were developed to match the Egyptian population by using multivariate linear regression to analyze all parameters and determine which parameters were most related to chronological age. The accuracy of these newly developed regression models was assessed using the ICC between all models and chronological age within the same group.
- The reliability of the new models was evaluated using the ICC for chronological age and new models within another group.

Statistical analysis

Data was fed to the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). The significance of the obtained results was judged at the 5% level. The tests used were: Intraclass Correlation Coefficient (ICC); for the agreement between chronological age and Foti models or with the new models. The ICCs, on the 95% confident interval, were classified using the system suggested by Koo and Li (Koo and Li 2016) as follows: values less than 0.50 Z poor agreement; 0.50 to less than 0.75 Z moderate agreement; 0.75 to 0.90 Z good agreement; above 0.90 Z excellent agreement. A '*p*' value less than 0.05 was considered statistically significant. ICC estimates and their 95% confident intervals were calculated, using the same SPSS statistical package, based on a mean-rating (k = 2), absolute agreement, 2-way mixed-effects model. Linear regression was employed to consider the role of different parameters in age estimation, where chronological age acted as the dependent variable and all other parameters were independent variables. It was used to help formulate new regression formulas needed for age estimation.

Results

A total of 1115 children participated in the current study. Group I consisted of 1000 children while group II consisted of 115 children. The sample description is listed in Table 1.

Accuracy of Foti regression models

Group I was evaluated by the three Foti regression models to show the ICC when compared with the chronological age (Table 2). For both the 6–< 9 years age group and the ≥ 9–14 years age group, the accuracy of Foti 1, 2 shows significant poor agreement with chronological age for both males and females.

Table 2 Intraclass Correlation Coefficient for chronological age and Foti models in group I ($n = 1000$)

	ICC coefficient	95% C.I	P
Overall ($n = 1000$)		LL UL	
Chronological age vs. Foti 1	0.619	0.580 – 0.656	< 0.001*
Chronological age vs. Foti 2	0.663	0.627 – 0.697	< 0.001*
Chronological age vs. Foti 3	0.710	0.678 – 0.740	< 0.001*
Age group			
Group 6—< 9 years ($n = 513$)			
Chronological age vs. Foti 1	0.127	0.041 – 0.211	0.002*
Chronological age vs. Foti 2	0.276	0.194 – 0.354	< 0.001*
Chronological age vs. Foti 3	0.646	0.593 – 0.694	< 0.001*
Group ≥ 9—14 years ($n = 487$)			
Chronological age vs. Foti 1	0.408	0.332 – 0.480	< 0.001*
Chronological age vs. Foti 2	0.389	0.311 – 0.462	< 0.001*
Chronological age vs. Foti 3	0.445	0.371 – 0.513	< 0.001*
Sex			
Male overall ($n = 484$)			
Chronological age vs. Foti 1	0.619	0.561 – 0.671	< 0.001*
Chronological age vs. Foti 2	0.660	0.606 – 0.707	< 0.001*
Chronological age vs. Foti 3	0.701	0.652 – 0.743	< 0.001*
Group 6—< 9 years ($n = 250$)			
Chronological age vs. Foti 1	0.174	0.051 – 0.291	0.003*
Chronological age vs. Foti 2	0.321	0.205 – 0.428	< 0.001*
Chronological age vs. Foti 3	0.653	0.575 – 0.719	< 0.001*
Group ≥ 9—14 years ($n = 234$)			
Chronological age vs. Foti 1	0.406	0.293 – 0.508	< 0.001*
Chronological age vs. Foti 2	0.389	0.274 – 0.492	< 0.001*
Chronological age vs. Foti 3	0.451	0.343 – 0.548	< 0.001*
Female ($n = 516$)			
Chronological age vs. Foti 1	0.622	0.566 – 0.672	< 0.001*
Chronological age vs. Foti 2	0.669	0.619 – 0.714	< 0.001*
Chronological age vs. Foti 3	0.719	0.675 – 0.758	< 0.001*
Group 6—< 9 years ($n = 263$)			
Chronological age vs. Foti 1	0.086	-0.035 – 0.205	0.081
Chronological age vs. Foti 2	0.235	0.117 – 0.346	< 0.001*
Chronological age vs. Foti 3	0.640	0.563 – 0.707	< 0.001*
Group ≥ 9—14 years ($n = 253$)			
Chronological age vs. Foti 1	0.417	0.309 – 0.513	< 0.001*
Chronological age vs. Foti 2	0.396	0.287 – 0.495	< 0.001*
Chronological age vs. Foti 3	0.441	0.336 – 0.535	< 0.001*

poor agreement < 0.50 moderate agreement 0.50—< 0.75

good agreement 0.75—0.90 excellent agreement > 0.90

CI Confidence interval, *LL* Lower limit, *UL* Upper Limit

* Statistically significant at $p \le 0.05$

Developing new regression models

The collected data was subjected to linear regression analysis to evaluate the variables. The variables that showed a high level of significance were used later in generating the three new models. (Tables 3, 4 and 5).

Table 3 shows Multivariate Linear regression analysis for the constant variables in Foti model 1 (upper & lower jaws) affecting chronological age in group I which resulted in developing a new equation after adding new independent variables. It was named (EGY I) for both jaws.

Table 3 Multivariate Linear regression analysis for Foti model 1 (upper & lower jaws) affecting chronological age in group I ($n = 1000$)

	B	SE	95% CI (LL-UL)	T	*P*
(Constant)	1.607	1.831	-1.985 – 5.199	0.878	0.380
Number of deciduous upper incisors	0.247	0.051	0.148 – 0.347	4.872	< 0.001*
Number of deciduous upper molars	-0.127	0.135	-0.393 – 0.139	-0.939	0.348
Number of permanent upper canines	–	–	–	–	–
Number of permanent upper first molars	0.000	0.062	-0.123 – 0.122	-0.008	0.994
Number of permanent upper second molars	0.231	0.075	0.084 – 0.378	3.082	0.002*
Number of upper third molars	–	–	–	–	–
Number of lower pre-molars	0.084	0.067	-0.048 – 0.215	1.251	0.211
Number of permanent lower second molars	0.194	0.075	0.048 – 0.341	2.600	0.009*
Number of lower third molars	–	–	–	–	–
Number of erupted third molars	–	–	–	–	–
Number of deciduous lower incisors	0.180	0.099	-0.015 – 0.375	1.816	0.070
Number of permanent lower canines	1.525	0.847	-0.138 – 3.188	1.799	0.072
Number of permanent upper incisors	0.793	0.047	0.700 – 0.886	16.746	< 0.001*
Number of permanent upper premolars	0.062	0.137	-0.207 – 0.330	0.451	0.652
Number of deciduous upper canines	0.114	0.062	-0.008 – 0.236	1.831	0.067
Number of permanent lower incisors	0.382	0.100	0.186 – 0.578	3.824	< 0.001*
Number of deciduous lower canines	1.360	0.847	-0.303 – 3.022	1.605	0.109
Number of deciduous lower molars	-0.044	0.059	-0.160 – 0.072	-0.740	0.460
Number of permanent lower first molars	0.424	0.088	0.251 – 0.596	4.822	< 0.001*
$R^2 = 0.775$, $F = 226.401$, $p < 0.001^*$					

poor agreement < 0.50 moderate agreement 0.50—< 0.75

good agreement 0.75—0.90 excellent agreement > 0.90

SE Standard Error, *C.I* Confidence interval, *LL* Lower limit, *UL* Upper Limit, *B* Unstandardized Coefficients, *F, p* f and *p* values for the model, R^2 Coefficient of determination, *t* t-test of significance

* Statistically significant at $p \leq 0.05$

EGY I equation: 1.607 + (0.247* Number of deciduous upper incisors) + (-0.127* Number of deciduous upper molars) + (0.0* Number of permanent upper 1st molars) + (0.231* Number of permanent upper 2nd molars) + (0.084* Number of lower premolars) + (0.194* Number of permanent lower 2nd molars) + (0.180* Number of deciduous lower incisors) + (1.525* Number of permanent lower canines) + (0.793* Number of permanent upper incisors) + (0.062* Number of permanent upper premolars) + (0.114* Number of deciduous upper canines) + (0.382* Number of permanent lower incisors) + (1.360* Number of deciduous lower canines) + (-0.044* Number of deciduous lower molars) + (0.424* Number of permanent lower 1st molars)

Normality of the residuals and Homoscedasticity for Foti model 1 as related to the chronological age in group I were plotted in Fig. 2 and Fig. 3 respectively.

Table 6 shows Intraclass Correlation Coefficient (ICC) for chronological age and EGY I (upper & lower jaws). There is good agreement between chronological age and EGY I with statistically significant difference.

Table 4 Multivariate Linear regression analysis for Foti model 2 (upper jaw) affecting chronological age in group I ($n = 1000$)

	B	SE	95% CI (LL-UL)	T	P
(Constant)	7.132	0.603	5.948 – 8.316	11.821	< 0.001*
Number of deciduous upper incisors	0.136	0.049	0.040 – 0.231	2.789	0.005*
Number of deciduous upper molars	-0.260	0.137	-0.529 – 0.010	-1.892	0.059
Number of permanent upper canines	–	–	–	–	–
Number of permanent upper first molars	0.105	0.061	-0.014 – 0.224	1.728	0.084
Number of permanent upper second molars	0.370	0.065	0.242 – 0.499	5.660	< 0.001*
Number of upper third molars	–	–	–	–	–
Number of permanent upper incisors	0.842	0.049	0.746 – 0.938	17.243	< 0.001*
Number of permanent upper premolars	0.025	0.141	-0.251 – 0.301	0.177	0.860
Number of deciduous upper canines	-0.084	0.058	-0.197 – 0.030	-1.448	0.148
$R^2 = 0.752$, $F = 429.777$, $p < 0.001^*$					

poor agreement < 0.50, moderate agreement 0.50—< 0.75

good agreement 0.75—0.90, excellent agreement > 0.90

SE Standard Error, *C.I* Confidence interval, *LL* Lower limit, *UL*, Upper Limit, *B* Unstandardized Coefficients, *F,p* f and *p* values for the model, R^2 Coefficient of determination, *t* t-test of significance

* Statistically significant at $p \leq 0.05$

EGY II equation: 7.132 + (0.136* Number of deciduous upper incisors) + (-0.260* Number of deciduous upper molars) + (0.105* Number of permanent upper 1st molars) + (0.370* Number of permanent upper 2nd molars) + (0.842* Number of permanent upper incisors) + (0.025* Number of permanent upper premolars) + (-0.084* Number of deciduous upper canines)

Table 5 Multivariate Linear regression analysis for Foti model 3 (lower jaw) affecting chronological age in group I ($n = 1000$)

	B	SE	95% CI (LL-UL)	t	p
(Constant)	3.353	2.224	-1.013 – 7.718	1.507	0.132
Number of lower premolars	0.313	0.077	0.161 – 0.464	4.055	< 0.001*
Number of permanent lower second molars	0.321	0.077	0.170 – 0.472	4.180	< 0.001*
Number of lower third molars	–	–	–	–	–
Number of erupted third molars	–	–	–	–	–
Number of deciduous lower incisors	0.102	0.122	-0.137 – 0.341	0.838	0.402
Number of permanent lower canines	0.900	1.042	-1.145 – 2.945	0.863	0.388
Number of permanent lower incisors	0.736	0.121	0.498 – 0.974	6.058	< 0.001*
Number of deciduous lower canines	0.489	1.041	-1.555 – 2.532	0.469	0.639
Number of deciduous lower molars	0.038	0.073	-0.106 – 0.182	0.520	0.603
Number of permanent lower first molars	0.759	0.107	0.549 – 0.968	7.098	< 0.001*
$R^2 = 0.649$, $F = 228.741$, $p < 0.001^*$					

poor agreement < 0.50, moderate agreement 0.50—< 0.75

good agreement 0.75—0.90, excellent agreement > 0.90

SE Standard Error, *C.I* Confidence interval, *LL* Lower limit, *UL* Upper Limit, *B* Unstandardized Coefficients, *F,p* f and *p* values for the model, R^2 Coefficient of determination, *t* t-test of significance

* Statistically significant at $p \leq 0.05$

EGY III equation: 3.353 + (0.313* Number of lower premolars) + (0.321* Number of permanent lower 2nd molars) + (0.102* Number of deciduous lower incisors) + (0.900* Number of permanent lower canines) + (0.736* Number of permanent lower incisors) + (0.489* Number of deciduous lower canines) + (0.038* Number of deciduous lower molars) + (0.759* Number of permanent lower 1st molars)

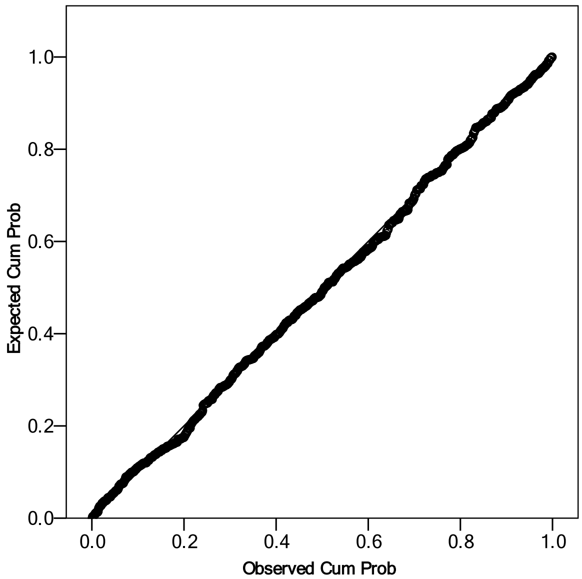

Fig. 2 P-P Plot of normality for Foti model 1 (upper & lower jaws) affecting chronological age in group I ($n=1000$)

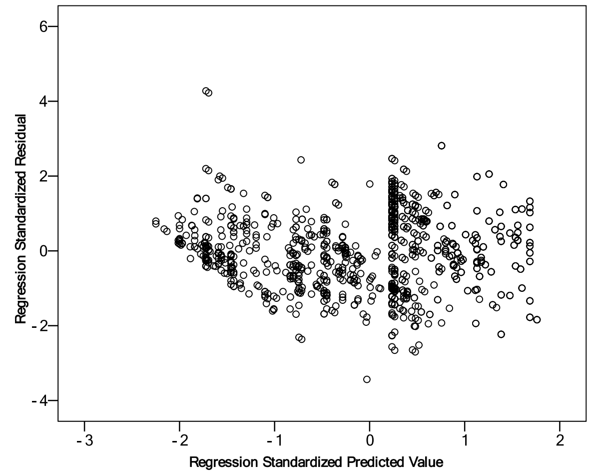

Fig. 3 Homoscedasticity for Foti model 1 (upper & lower jaws) affecting chronological age in group I ($n=1000$)

Table 7 shows comparison between chronological age and estimated age by EGY I (upper & lower jaws) in group I ($n=1000$) at different class intervals.

The same steps were followed in Table 4. It shows Multivariate Linear regression analysis for the constant variables in Foti model 2 (upper jaw) affecting chronological age in group I which resulted in developing a new equation for the upper jaw after adding new independent variables. The new equation was named (EGY II) for the upper jaw.

Normality of the residuals and Homoscedasticity for Foti model 2 as related to the chronological age in group I were plotted in Fig. 4 and Fig. 5 respectively.

Table 8 shows Intraclass Correlation Coefficient (ICC) for chronological age and EGY II (upper jaw). There is good agreement between chronological age and EGY II with statistically significant difference.

Table 9 shows comparison between chronological age and estimated age by EGY II (upper jaw) in group I ($n=1000$) at different class intervals.

The same procedure was performed in Table 5. It shows multivariate linear regression analysis for the constant variables in Foti model 3 (lower jaw) affecting chronological age in group I which resulted in developing a new equation for the lower jaw after adding new independent variables. The new equation was named (EGY III) for the lower jaw.

Normality of the residuals and Homoscedasticity for Foti model 3 as related to the chronological age in group I were plotted in Fig. 6 and Fig. 7 respectively.

Table 10 shows Intraclass Correlation Coefficient (ICC) for chronological age and EGY III (lower jaw). There is good agreement between chronological age and EGY III with statistically significant difference.

Table 11 shows comparison between chronological age and estimated age by EGY III (lower jaw) in group I ($n=1000$) at different class intervals.

Reliability of the new regression models

The degree of accuracy of the new regression models for age estimation as compared to the chronological age was evaluated in a group of 115 child (group II) in Table 12. They were of the same age range 6- 14 years and having the same inclusion criteria. Accuracy was analyzed by ICC to categorise their level of agreement. In Table 12: 6–<9 years age group, the accuracy of EGY I and II shows significant moderate to good agreement with chronological age. Whereas accuracy of EGY III shows significant poor to moderate agreement. While ≥9–14 years age group, the accuracy of EGY I shows significant poor to good agreement with age. Whereas accuracy of EGY II and III shows significant poor to moderate agreement. The accuracy of EGY I, II, III shows significant moderate to good agreement with male children. While the accuracy of EGY I and II shows significant moderate to good agreement with female children. Whereas accuracy of EGY III shows significant poor to good agreement with females.

Confidence intervals between chronological and estimated age by EGY I, II and III are shown in Bland Altman plots, where the level of agreement for EGY I lies between -1.6 and 1.6 (Fig. 8) while for EGY II, it lies between -1.7 and 1.7 (Fig. 9) and for EGY III it is between -2.0 and 2.0 (Fig. 10).

Table 6 Intraclass Correlation Coefficient for chronological age with EGY I (upper& lower jaws)

	ICC coefficient	95% C.I	*P*
Chronological age vs. EGY I (upper& lower jaws)		LL UL	
	0.873	0.858 – 0.887	< 0.001*

poor agreement < 0.50, moderate agreement 0.50—< 0.75

good agreement 0.75—0.90, excellent agreement > 0.90

CI Confidence interval, *LL* Lower limit, *UL* Upper Limit

* : Statistically significant at $p \leq 0.05$

Table 7 Comparison between chronological age and estimated age by EGY I (upper & lower jaws) in group I ($n = 1000$) at different class intervals

	No	Chronological age	Estimated age	Difference	T	*p*
Age group		**Mean ± SD**	**Mean ± SD**	**Mean ± SD**		
6 – < 7	**149**	6.43 ± 0.22	6.71 ± 0.56	0.28 ± 0.57	6.132*	< 0.001*
7 – < 8	**145**	7.45 ± 0.24	7.87 ± 0.77	0.41 ± 0.76	6.524*	< 0.001*
8 – < 9	**219**	8.47 ± 0.26	8.81 ± 0.79	0.34 ± 0.75	6.631*	< 0.001*
9 – < 10	**106**	9.60 ± 0.33	9.71 ± 0.84	0.11 ± 0.88	1.305	0.195
10 – < 11	**258**	10.48 ± 0.26	10.12 ± 0.64	-0.36 ± 0.68	8.518*	< 0.001*
11 – < 12	**87**	11.45 ± 0.26	10.85 ± 0.72	-0.60 ± 0.63	8.877*	< 0.001*
12 – < 13	**36**	12.42 ± 0.25	11.27 ± 0.42	-1.15 ± 0.52	13.420*	< 0.001*

t Paired t-test, *p p* value for comparing Chronological age and estimated age

* Statistically significant at $p \leq 0.05$

Discussion

The determination of a child's age is of immense value in medicolegal issues or forensic dentistry. For several decades, radiographic methods have been used to identify dental age in children. The most popular of these methods is the Demirjian method (Panchbhai 2011). It is based on the evaluation of developmental stage and transforming them into scores, whose sum defines the dental age through definite tables (Demirjian et al. 1973). This method yielded reliable results on French-Canadian children aged 3–16 years and on Norwegian children aged 5.5–12.5 years. However, it was proven not to be reliable with Egyptian children aged 3–10 years (Moness Ali et al. 2019). Furthermore, socioeconomic status could have an impact on teeth development. Several studies have shown that children of low socioeconomic status may have delayed eruption relative to those of higher socioeconomic status, which has been attributed to malnutrition (Holman and Yamaguchi 2005). Nevertheless, dental development is less affected than skeletal development by either malnutrition or hormonal disorders. Moreover, all radiographic methods have limitations that can be summarized as follows: they are based on the use of radiographs, which comes with the hazards of an x-ray dose. Additionally, identifying the exact tooth developmental stage could be subjective from one observer to another. Despite this, dental development is a good and reliable indicator of age estimation. According to Biggerstaff, forensic dentists can estimate age by systematically observing the developing dentition (Biggerstaff 1977).

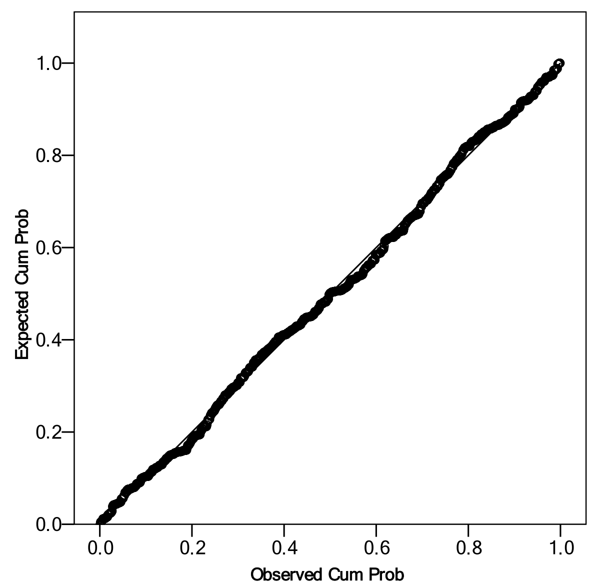

Fig. 4 P-P Plot of normality for Foti model 2 (upper jaw) affecting chronological age in group I ($n = 1000$)

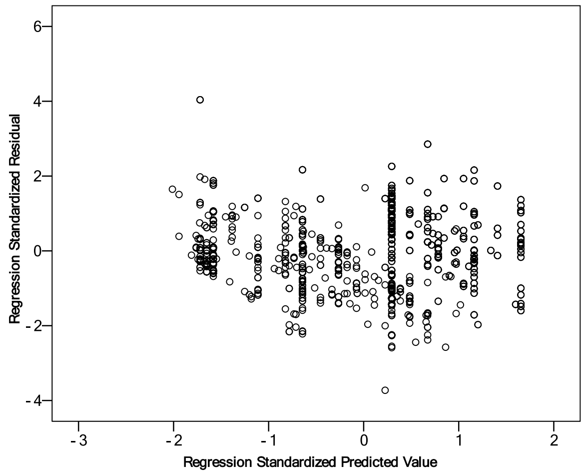

Fig. 5 Homoscedasticity for Foti model 2 (upper jaw) affecting chronological age in group I ($n = 1000$)

Hence, a reliable method that does not involve the use of radiographic techniques in children would be of great benefit to either forensic dentistry or even to dentists in a rural setup. A study by Kaul et al. suggested that the erupted teeth could be used to estimate age in primary dentition. They used probit analysis to calculate age according to tooth emergence in 312 children (Kaul et al. 1992). Another study by Camps concluded that age estimation can be achieved by observing the stages of eruption of both primary and mixed dentitions. Although he pointed out that eruption itself only gives an indication of age due to wide variations of growth (Camps and Lucas 1976). On the other hand, the sequence of eruption and the teeth present in the oral cavity were shown to be significantly independent of environmental influence, providing an accurate estimated age and as good as the Demirjian method (Townsend and Hammel 1990). While different populations showed variable eruption patterns emphasizing the role of genetics as an important factor in the tooth eruption sequence, conflicting results have been reported regarding this role (Diamanti and Townsend 2003; Elhiny et al. 2018; Sharma 2014; Šindelářová and Broukal 2019). Nevertheless, there are several studies that have been based on the number of erupted teeth to estimate age (Gillett 1997; Kumar and Sridhar 1990). Foti et al. (Foti et al. 2003) derived three regression models by counting erupted teeth. Their method proved to be reliable in estimating the age of the French population between 6 to 20 years of age.

Table 8 Intraclass Correlation coefficient for chronological age and EGY II (upper jaw)

	ICC coefficient	95% C.I	*P*
Chronological age vs. EGY II (upper jaw)		LL UL	
	0.858	0.841 – 0.874	< 0.001*

poor agreement < 0.50, moderate agreement 0.50—< 0.75

good agreement 0.75—0.90, excellent agreement > 0.90

CI Confidence interval, *LL* Lower limit, *UL* Upper Limit

* Statistically significant at $p \leq 0.05$

Table 9 Comparison between chronological age and estimated age by EGY II (upper jaw) in group I ($n = 1000$) at different class intervals

	No	Chronological age	Estimated age	Difference	t	*P*
Age group		**Mean ± SD**	**Mean ± SD**	**Mean ± SD**		
6 – < 7	**149**	6.43 ± 0.22	6.82 ± 0.52	0.39 ± 0.57	8.351*	< 0.001*
7 – < 8	**145**	7.45 ± 0.24	7.82 ± 0.83	0.37 ± 0.82	5.384*	< 0.001*
8 – < 9	**219**	8.47 ± 0.26	8.84 ± 0.85	0.37 ± 0.82	6.615*	< 0.001*
9 – < 10	**106**	9.60 ± 0.33	9.67 ± 0.91	0.07 ± 0.95	0.737	0.463
10 – < 11	**258**	10.48 ± 0.26	10.10 ± 0.63	-0.38 ± 0.69	8.899*	< 0.001*
11 – < 12	**87**	11.45 ± 0.26	10.85 ± 0.64	-0.60 ± 0.54	10.305*	< 0.001*
12 – < 13	**36**	12.42 ± 0.25	11.10 ± 0.53	-1.33 ± 0.56	14.176*	< 0.001*

t Paired t-test, *p p* value for comparing Chronological age and estimated age

* Statistically significant at $p \leq 0.05$

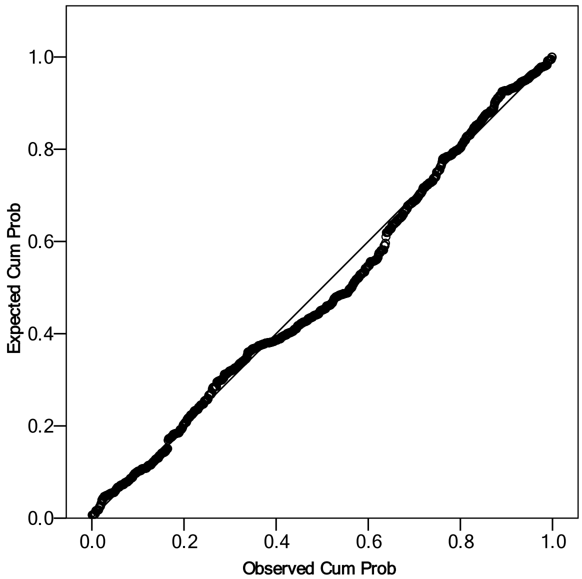

Fig. 6 P-P Plot of normality for Foti model 3 (lower jaw) affecting chronological age in group I ($n = 1000$)

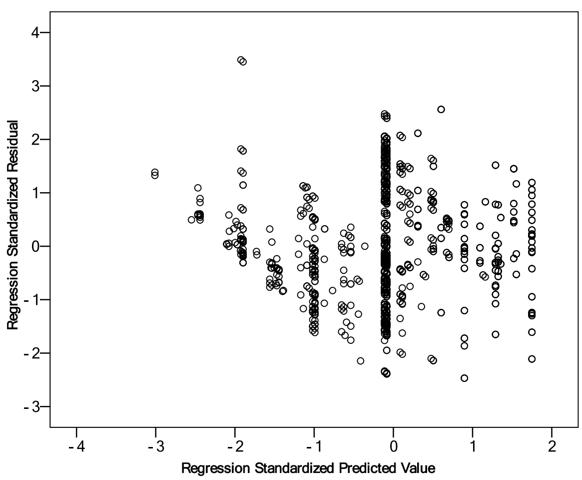

Fig. 7 Homoscedasticity for Foti model 3 (lower jaw) affecting chronological age in group I ($n = 1000$)

The current study consisted of a sample of 1115 child ranging in age from 5 to 14 years. They were normal children with no underlying genetic, endocrinal, or nutritional diseases to avoid any variability in the results as these factors have a significant effect on dental development. Additionally, many studies have suggested that dental development varies between different ancestries, so the rate and timing of development differ among various populations (AlQahtani et al. 2010; Blenkin and Evans 2010; Kırzıoğlu and Ceyhan 2012). Consequently, in the present study, the target was to address the Egyptian children population as a different ancestral/racial group than the French population. This was achieved by measuring the accuracy of a well-established mathematical method for age estimation and by developing a modified method that could be better applied to Egyptian children. One of the merits of using a mathematical method is the elimination of observer variations that could occur while using other age estimation methods. These variations are attributed to subjective assessments of tooth development.

Oral cavity examination was conducted on all children participating in the study. This visual examination has the advantage of being non-destructive and non-invasive (Panchbhai 2011). The parameters analyzed in the current study were the teeth present in the oral cavity as they are already parameters of the Foti regression models. However, other parameters were also incorporated into the analysis as they could influence the development of new models suitable for the Egyptian population. In the current study, the age range was between 6 and 14 years. The lower limit was chosen to ensure the presence of at least one erupted permanent tooth. The upper limit was set at 14 years to guarantee the inclusion of the second permanent molar as a variable in the regression model (Balaraj and Nithin 2010).

Pearson correlation coefficient, paired t test, and Bland–Altman plot have been used to evaluate the reliability between different measurements in various studies (Bruton et al. 2000). Reliability is defined as the extent to which measurements can be replicated (Koo and Li 2016). It reflects the degree of correlation and agreement between measurements. Its value ranges between 0 and 1, with values closer to one representing stronger reliability. A systematic review was conducted on different statistical methods used for testing reliability. The study concluded that ICC is the most accurate method that could be used to assess the reliability of measurements as they are alike in reflecting both the degree of correlation and agreement between measurements (Zaki et al. 2013). Whereas paired t test and Bland–Altman plot are methods for analyzing agreement, and Pearson correlation coefficient is only a measure of correlation. Therefore, ICC was used in the current study to determine the agreement between chronological age and estimated age by the mathematical regression models.

Table 10 Intraclass Correlation Coefficient for chronological age and EGY III (lower jaw)

	ICC coefficient	95% C.I	p
		LL UL	
Chronological age vs. EGY III (lower jaw)	0.787	0.762 – 0.809	< 0.001*

poor agreement < 0.50, moderate agreement 0.50—< 0.75

good agreement 0.75—0.90, excellent agreement > 0.90

CI Confidence interval, *LL* Lower limit, *UL* Upper Limit

* Statistically significant at $p \leq 0.05$

Table 11 Comparison between chronological age and estimated age by EGY III (lower jaw) in group I ($n = 1000$) at different class intervals

	No	Actual age	Predicted age	Difference	t	P
Age group		**Mean ± SD**	**Mean ± SD**	**Mean ± SD**		
6 – < 7	**149**	6.43 ± 0.22	6.98 ± 0.87	0.55 ± 0.82	8.277*	< 0.001*
7 – < 8	**145**	7.45 ± 0.24	8.39 ± 0.82	0.94 ± 0.78	14.434*	< 0.001*
8 – < 9	**219**	8.47 ± 0.26	8.77 ± 0.62	0.30 ± 0.61	7.256*	< 0.001*
9 – < 10	**106**	9.60 ± 0.33	9.50 ± 0.89	-0.10 ± 0.94	1.084	0.281
10 – < 11	**258**	10.48 ± 0.26	9.89 ± 0.87	-0.60 ± 0.91	10.581*	< 0.001*
11 – < 12	**87**	11.45 ± 0.26	10.58 ± 0.99	-0.87 ± 0.90	9.032*	< 0.001*
12 – < 13	**36**	12.42 ± 0.25	11.22 ± 0.45	-1.21 ± 0.55	13.177*	< 0.001*

t Paired t-test, *p p* ` for comparing Chronological age and estimated age

* Statistically significant at $p \leq 0.05$

The results of the study revealed that analyzing Foti regression models versus chronological age had ICC values less than 0.5 (poor agreement) which led to the development of new regression models. This was achieved through linear regression analysis to specify the valid parameters for the new models. Higher ICCs between 0.75 to 0.9 (good agreement) were recorded in group II when the new models were analyzed versus chronological age. Model I (EGY I) showed the best results with all categories followed by the second model (EGY II) whereas the third model (EGY III) showed a few skewed results. Hence the null hypothesis was not rejected.

Study limitations

One limitation of this study is that it was conducted in a restricted area, specifically one governorate in Egypt. This could be addressed in future studies by using a larger and more randomly selected sample from different regions of the country. Additionally, it would have been valuable if the study had reported the standard deviation for each age group rather than using an overall confidence interval to indicate the accuracy of the predictions.

Conclusions

Within the limitations of this study, it can be concluded that the newly formulated regression models are reliable for estimating the age of Egyptian children during the mixed dentition stage. A good agreement was found between the estimated age obtained from the first two models and the chronological age. However, model EGY III had the least agreement, suggesting that age estimation may be more accurate using only the first two models.

Recommendations

As a result of this study, it is recommended that further investigations be conducted to compare the use of mathematical regression models with other dental age estimation methods for Egyptian children. A larger sample within each age group would provide more concrete results. Given that all mathematical processes and entries were performed using Microsoft Excel, this could greatly

Table 12 Intraclass Correlation Coefficient for chronological age and new models in group II ($n = 115$)

	ICC coefficient	95% C.I	*P*
Overall ($n = 115$)		LL UL	
Chronological age vs. EGY I	0.819	0.749 – 0.871	< 0.001*
Chronological age vs. EGY II	0.803	0.727 – 0.860	< 0.001*
Chronological age vs. EGY III	0.691	0.582 – 0.776	< 0.001*
Age group			
Group 6—< 9 years ($n = 84$)			
Chronological age vs. EGY I	0.724	0.604 – 0.812	< 0.001*
Chronological age vs. EGY II	0.699	0.571 – 0.794	< 0.001*
Chronological age vs. EGY III	0.616	0.464 – 0.733	< 0.001*
Group ≥ 9—14 years ($n = 31$)			
Chronological age vs. EGY I	0.544	0.240 – 0.751	0.001*
Chronological age vs. EGY II	0.514	0.200 – 0.732	0.001*
Chronological age vs. EGY III	0.508	0.193 – 0.728	0.001*
Sex			
Male overall ($n = 58$)			
Chronological age vs. EGY I	0.812	0.701 – 0.884	< 0.001*
Chronological age vs. EGY II	0.783	0.659 – 0.866	< 0.001*
Chronological age vs. EGY III	0.723	0.573 – 0.826	< 0.001*
Group 6—< 9 years ($n = 40$)			
Chronological age vs. EGY I	0.624	0.391 – 0.782	< 0.001*
Chronological age vs. EGY II	0.589	0.343 – 0.759	< 0.001*
Chronological age vs. EGY III	0.529	0.264 – 0.720	< 0.001*
Group ≥ 9—14 years ($n = 18$)			
Chronological age vs. EGY I	0.511	0.072 – 0.784	0.013*
Chronological age vs. EGY II	0.510	0.071 – 0.783	0.013*
Chronological age vs. EGY III	0.452	-0.004 – 0.753	0.026*
Female overall ($n = 57$)			
Chronological age vs. EGY I	0.827	0.724 – 0.895	< 0.001*
Chronological age vs. EGY II	0.827	0.722 – 0.894	< 0.001*
Chronological age vs. EGY III	0.643	0.462 – 0.773	< 0.001*
Group 6—< 9 years ($n = 44$)			
Chronological age vs. EGY I	0.806	0.670 – 0.889	< 0.001*
Chronological age vs. EGY II	0.796	0.655 – 0.883	< 0.001*
Chronological age vs. EGY III	0.688	0.494 – 0.817	< 0.001*
Group ≥ 9—14 years ($n = 13$)			
Chronological age vs. EGY I	0.481	-0.070 – 0.807	0.041*
Chronological age vs. EGY II	0.419	-0.146 – 0.778	0.068
Chronological age vs. EGY III	0.500	-0.044 – 0.815	0.034*

EGY I: Upper and Lower model
EGY II: Upper model
EGY III: Lower model
poor agreement < 0.50, moderate agreement 0.50—< 0.75
good agreement 0.75—0.90, excellent agreement > 0.90
CI Confidence interval, *LL* Lower limit, *UL* Upper Limit
* Statistically significant at $p \leq 0.05$

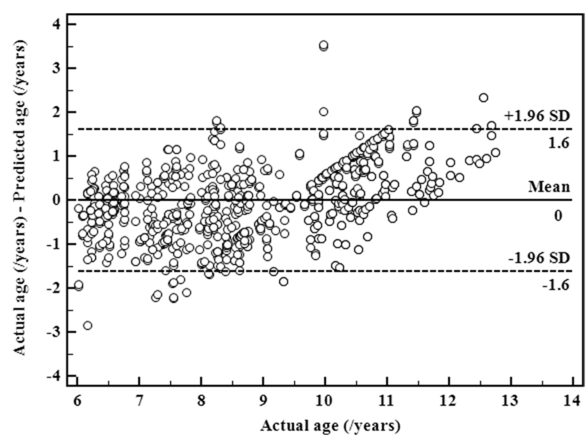

Fig. 8 Bland Altman plot between chronological and estimated age using EGY I (upper & lower jaws) in group I ($n = 1000$)

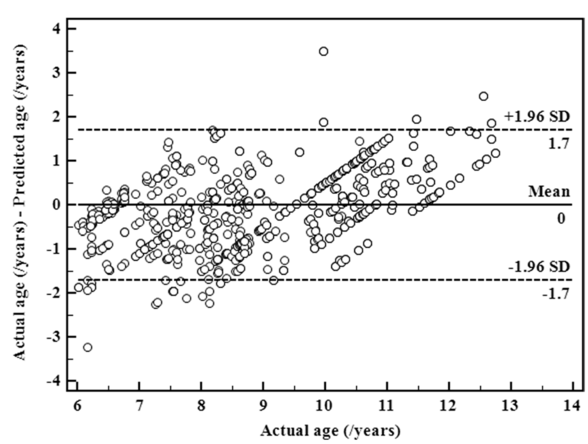

Fig. 9 Bland Altman plot between chronological and estimated age using EGY II (upper jaw) in group I ($n = 1000$)

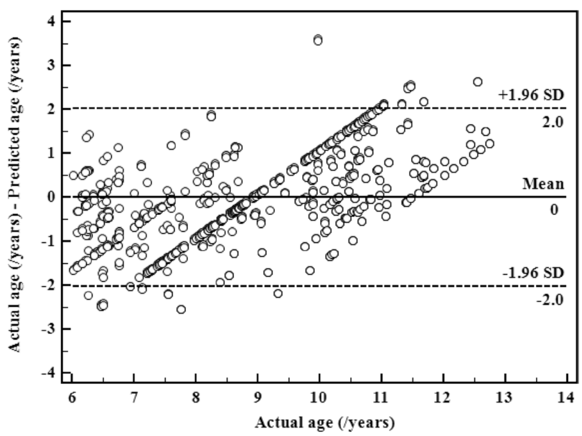

Fig. 10 Bland Altman plot between chronological and estimated age using EGY III (lower jaw) in group I ($n = 1000$)

benefit forensic odontologists or any examiners by allowing them to simply record the presence or absence of a tooth and immediately obtain an estimated dental age. It is also recommended to develop a user-friendly application incorporating these models to enable forensic odontologists to attain reliable and immediate results while avoiding any calculation errors.

Abbreviations

ICC Intraclass Correlation Coefficient
SPSS Statistical Package for Social Sciences

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Authors' contribution

This is the work of two authors. RSS: conception of the study, design of the study, data collection, data analysis and interpretation, critical review/proof reading and finalizing manuscript. OMA: literature review, manuscript preparation, critical review/proof reading and finalizing manuscript. Both authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This is a cross sectional study. It was approved by the Research Ethics Committee, Pharos University in Alexandria, Egypt (# PUA02202208283039) and was accomplished with adherence to the tenets of the Declaration of Helsinki 1964 and its later amendments. A written informed consent to participate, after explanation of the study and its aim, was obtained from all the parents or legal guardians of subjects participating in the study.

Consent for publication

Not applicable.

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

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