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Usefulness of Combining Clinical and Radiological Dental Findings for a More Accurate Noninvasive Age Estimation

ABSTRACT: The aim of this study was to establish correlations of clinical and radiological dental findings, alone or in combination, with chronological age in adults. Dental findings and orthopantomograms of 984 patients (aged 20–60 years; 524 females/460 males) were analyzed. DMF-T index and distance (alveolar bone level, ABL) between cemento-enamel junction and alveolar bone margin were recorded. Additionally, clinical and radiological findings at each tooth crown and root were collected according to the actual status of destruction and restoration, and a total score for each dentition (TSD) was calculated. After univariate correlation analysis, correlation coefficients for ABL and TSD were improved by using square root (sqrt). However, the determination accuracy was still not satisfactory; 90% of the residuals were in the range of about $\pm$ 10. The present study showed that clinical and radiological dental findings could not be used, not even in combination, for accurate age estimation as a single method, but that they could support other methods.

KEYWORDS: forensic science, forensic odontology, noninvasive, age estimation, clinical, radiological, dental findings, OPG

Mental maturity, and hence culpability, including the capacity for autonomous choice, self-management, risk perception, and the calculation of future, are dependent on brain development. Based on this biological maturity, the minimum age for marriage, driving, voting, and also criminal responsibility is set in different countries between the ages of 15 and 21 years. However, in countries with a high number of immigrants, asylum seekers, or refugees, there are frequently people without a legal pass, identification card, or certificate of birth. Some of them are trying to change their status in a criminal court with false statements or witnesses. In such cases, age determination will be necessary to evaluate the accuracy of this information.

For age estimation, different methods are available; however, invasive methods using extracted teeth, ribs, or femur cannot be used in living individuals (1,2). Assessment of sexual and skeletal maturation, radiological examination of bones, and also clinical and radiological examination of the dentition are noninvasive ways to determine the age (3–5). Dental age estimation can be based on different properties of the dentition. Diverse parameters of the dental cementum and dentin can be determined using extracted teeth of corpses (2,6,7). Methods based on the measurements of the pulp/tooth and root/tooth ratios, root development, or periodontal changes on dental radiographs, but also the clinical evaluation of attrition, tooth colour, and gingival recession are methods that can be applied to dead and living individuals (3,8–15). The studies based on the variations in pulp/tooth ratio demonstrated statistically significant correlations between the chronological age and the ratios of the pulp to root width or to tooth area and lead to errors of about $\pm$ 10 years in age estimation for 95% of the individuals (11,13,16). Recording of dental attrition at molars also resulted in discrepancies within $\pm$ 5 years (9,12,14,17). In children, adolescents, and young adults, the radiographic assessment of developing permanent teeth is another facility to determine the age (18,19). However, the accuracy of age estimation, using the stages of permanent teeth development, decreases with increasing age; discrepancies of about $\pm$ 2 years to chronological age were demonstrated in children by using the development stages of permanent teeth (20). In adolescents, the radiological assessment of the third molars leads to a standard deviation of about 1–4 years, but due to aplesia of all wisdom teeth in 5.5–6.6% of the population such a system cannot always be used (10,21–25). When using methods based on dental development, age has to be determined with regard to genetic and nutritional differences. The Demirjian standard based on the tooth maturation of a French-Canadian collective is an established method for age estimation (26,27). Nevertheless, this method cannot be applied to all ethnic groups (18,28–32).

Although age estimation using different dental methods is feasible with discrepancies of 5–10 years to the chronological age, a more accurate noninvasive method for age determination is required in living individuals. The aim of this study was to establish correlations of clinical and radiological dental findings with the chronological age of adults in a middle European population and to develop a method for age assessment using these findings, which can be collected by a dentist without special knowledge of forensic sciences.

Materials and Methods

The dental findings and orthopantomograms (OPG) of 984 patients (aged 20–60 years) attending a university dental clinic were analyzed in this study. The 524 females (median age: 35 years)

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TABLE 1—*Scores according to the destruction, restoration, and therapy needs of the tooth crowns and roots.*

Clinical Finding at the Tooth Crown	Score	Radiological Finding at the Tooth Root	Score
Without pathological change	0	Without pathological change	0
Decayed	1	Periradicular lesion	1
Filled*	2	Root canal filling	2
Decayed and filled	3	Root canal filling with periradicular lesion	3
Prosthetic restoration†	4	Endodontic surgery	4
Prosthetic restoration and decayed	5		
Fractured	6		
Missing	10		

*Restorations with amalgam, adhesive materials, dental cements, or inlay.
†Restorations with metal or metal ceramic crowns, onlays, and overlays.

and 460 males (median age: 36 years) of mostly middle European origin (93%) were patients without a systemic disease, long-term medical therapy, or medication.

The OPGs were produced with ORTHOPHOS DS (Siemens AG Berlin, München, Germany; 60 kV, 9 mA) ($n = 800$) and ORTHOPHOS CD (Siemens; 90 kV, 12 mA) ($n = 200$) in a dental practice for oral surgery and in the department of dental radiology of the university dental clinic.

The caries prevalence was determined using the DMF-T index at 28 teeth. Additionally, the clinical and radiological findings at each tooth crown and root were recorded according to the actual status of the destruction and restoration (Table 1). A total score for each dentition (TSD) was calculated as a summation of the scores representing the actual status of each tooth crown and root.

The distance between the cemento-enamel junction and the alveolar bone margin (alveolar bone level, ABL) was measured on the OPGs using a 10-times magnifying glass mesially and distally of the teeth. The mean value of ABL in mm was calculated for each dentition. Patients with aggressive forms of periodontitis ($n = 30$) were excluded from analysis considering the ABL.

After the univariate correlation analysis of each variable (DMF-T, ABL, TSD) with the chronological age separately, an improvement of the estimation for the dependent variable "age" was attempted by combining different clinical and radiological variables.

The statistical evaluation of the data was performed using the SPSS program (version 12) at the Institute for Medical Biometrics, Epidemiology and Informatics, Johannes–Gutenberg University, Mainz. Spearman's rank and Pearson's correlation coefficients of clinical and radiological findings (DMF-T, ABL, TSD) with the chronological age were determined. ABL and TSD were transformed using square root (sqrt) to obtain an almost linear relation to age. Linear regression analyses were performed to verify the possibility of an age calculation using the data. Furthermore, the model with the highest goodness of fit r^2 was used for the calculation of model-based 95% prognosis intervals. As the aim of this study was age estimation and not the prognosis, the term "estimation limits" was used instead of the "prognosis interval."

Results

The analyses of the data showed only slight differences between the genders. However, determination accuracy for the dependent variable "age" was improved if models were built separately for males and females. The caries prevalence, the mean ABL, and the total of the scores for dentitions according to the stages of the destruction and restoration increased with the chronological age of the individuals (Table 2). The correlation coefficients for DMF-T, ABL, and TSD with the dependent variable "age" were high (Spearman's r: 0.624–0.757). The correlation coefficients for ABL and TSD were improved when their square root was used (Table 3).

DMF-T and sqrt-TSD were highly correlated (Pearson's $r = 0.914$); thus, one of these parameters was sufficient for age calculation. The goodness of fit increased only in the third decimal when considering DMF-T additional to sqrt-TSD and sqrt-ABL (Table 4). Thus, sqrt-TSD and sqrt-ABL were chosen for the age calculation model. The models for males (M) or females (F) were calculated as:

$$\mathrm{M}: \text{ age} = 22.731 + 6.641 \times \text{sqrt-ABL} + 1.170 \times \text{sqrt-TSD}$$
$$\mathrm{F}: \text{ age} = 20.241 + 7.159 \times \text{sqrt-ABL} + 1.347 \times \text{sqrt-TSD}$$

When using these models, the determination accuracy of age in females was slightly better than in males. However, the determination accuracy was not satisfactory as the 2.5% and 97.5% percentiles of the residuals for all subjects were -14.02 to 16.54 years for males and -12.50 to 15.29 years for females; 90% of the residuals were in the range of about ± 10 years. The estimated age using sqrt-ABL and sqrt-TSD showed a steeper increase in women than in men; also, the estimation limits were slightly narrower for females than for males (Fig. 1). The 95% estimation limits were calculated using the models with sqrt-ABL and sqrt-TSD, exemplarily, according to TDS and ABL for only

TABLE 2—*Median value and first and third quartile of caries prevalence (DMF-T), alveolar bone level (ABL), and of the total scores for dentitions according to the destruction and restoration of the tooth crowns and roots (TSD) in different age groups for both genders.*

Age (in years)	Gender	DMF-T		ABL		TSD	
		n	Median (Q1–Q3)	*n*	Median (Q1–Q3)	*n*	Median (Q1–Q3)
20–29	Male	142	10.5 (6–16)	139	0 (0–0)	142	29.5 (14–45)
	Female	186	9 (5–14)	185	0 (0–0)	186	23.5 (12–44)
	Total	328	10 (5–15)	324	0 (0–0)	328	26 (12–44)
30–39	Male	131	16 (12–20)	122	0 (0–1.5)	131	51 (33–86)
	Female	135	16 (12–19)	126	0 (0–1.5)	135	56 (36–85)
	Total	266	16 (12–19)	248	0 (0–1.5)	266	54.5 (34–85)
40–49	Male	96	20 (15–23)	94	3 (2–4)	96	90 (60–136)
	Female	103	21 (17–23)	98	3 (2–4)	103	94 (62–143)
	Total	199	20 (16–23)	192	3 (2–4)	199	93 (61–136)
50–60	Male	91	20 (17–24)	90	3 (2–5)	91	113 (78–176)
	Female	100	22 (19–26)	100	3 (2–4)	100	138 (95–190)
	Total	191	21 (18–26)	190	3 (2–4)	191	124 (84–181)

TABLE 3—*Spearman's and Pearson's correlation coefficients for the single variables and the square root (sqrt) of alveolar bone level (ABL) and total scores for dentitions (TSD) to the dependent variable "age."*

Variables	*n*	Spearman's Correlation Coefficient	Pearson's Correlation Coefficient
DMF-T	984	0.624	0.614
ABL	954	0.757	0.686
sqrt (ABL)		0.757	0.756
TSD	984	0.720	0.675
sqrt (TSD)		0.720	0.701

the eight groups that had the highest numbers of subjects (Table 5). The 95% estimation limits of both genders were ± 15 years.

Discussion

In the present study, the selection of the dental parameters used for age assessment was based on their implementation in the dental practice and on their reproducibility. With the exception of the exact measurement of the alveolar bone loss on the radiographs, all the findings used in the survey were part of the routine dental examination.

Radiological examination is a simple, nondestructive method to obtain clinically invisible findings in medicine. In dental practice, intra-oral radiography and panoramic tomography are widely used X-ray techniques. In the present study, the OPG was selected for the radiographic assessment of the dental findings because of the possibility of the evaluation of all teeth and roots, but also of the alveolar bone in both jaws, and several measurements can be performed on the same X-rays. Furthermore, OPG is a standard technique with a high reproducibility, while the quality and diagnostic acceptability of the intra-oral radiographs are dependent on the techniques used and the practical training of the personnel (33). In different surveys on age determination, intra-oral radiographs were used for the assessment of the size of the pulp as well as of the diameter and length changes of the roots (3,34). Drusini et al. (13) used an index for age determination on intra-oral radiographs based on the ratio of the crown height to the height of the coronal pulp cavity in premolars and molars, and obtained errors within ± 5 years in about 80% of their sample. The reliability and reproducibility of the findings on an X-ray are important when trying to establish an accurate noninvasive method for age determination. Although Molander (35) considered the agreement between panoramic and intraoral radiography as insufficient to diagnose periapical lesions, marginal bone loss, and caries, Mattick et al. (36) found that in only 22 of 1169 OPGs essential findings were completely missing. Larheim and Svanaes (37) and Lien and Soh (38) measured higher mean vertical lengths on 18–22% of OPGs, but Persson et al. (39) showed that the findings of the ABLs on OPGs and intra-oral radiographies are highly comparable. In another survey, Larheim et al. (40) showed repeatedly on OPGs errors from 0.43 to 0.56 mm of tooth length measurements, and they suspected reference points as the main source of measurement error. Also, in the present study, despite the usage of a magnifying glass, the determination of the reference points at the cemento-enamel junction was difficult. To minimize the measurement error, which can also be caused by inter-observer disa-

TABLE 4—*Regression coefficients and goodness of fit for linear regression (dependent variable "age") for the different models.*

	Regression Coefficient m/f	*p*-Value	Goodness of Fit (r^2), m/f
Model 1			0.585/0.679
DMF-T	7.865/7.987	<0.0005/<0.0005	
Sqrt (ABL)	0.432/0.589	<0.0005/<0.0005	
Model 2			0.608/0.691
sqrt (TSD)	6.641/7.159	<0.0005/<0.0005	
Sqrt (ABL)	1.170/1.347	<0.0005/<0.0005	
Model 3			0.609/0.692
DMF-T	– 0.147/0.142	0.241/0.199	
Sqrt(TSD)	1.461/1.084	<0.0005/<0.0005	
Sqrt(ABL)	6.481/7.186	<0.0005/<0.0005	

m, male; f, female; sqrt, square root; DMF-T, caries prevalence; ABL, mean alveolar bone level; TSD, total score for the dentition according to the destruction, restoration, and therapy needs of the tooth crowns and roots.

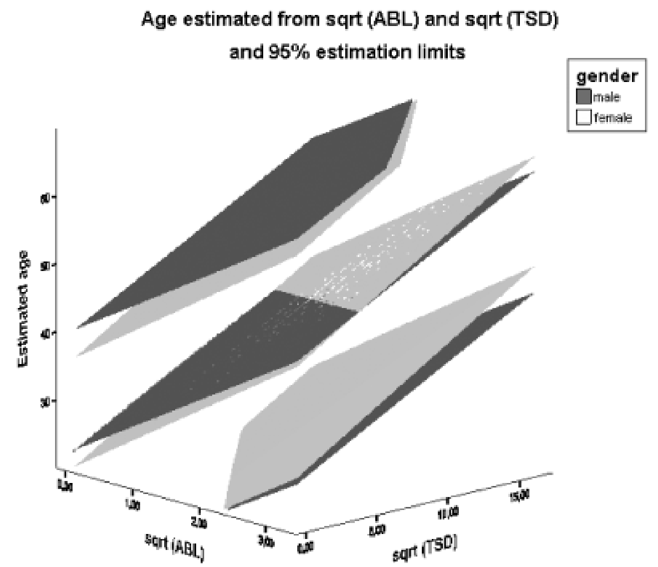

FIG. 1—*Planes demonstrating the estimation of age according to the model with square root (sqrt) alveolar bone level (ABL) and sqrt total score for each dentition (TSD). The intersection of the two planes in the middle shows that the increase in the estimated age is steeper in women (light gray plane) compared with men (dark gray plane). The upper and lower planes show the 95% estimation limits; these are slightly narrower for the women than for the men.*

TABLE 5—*Examples for age estimation and 95% estimation limits based on the linear regression with sqrt-ABL and sqrt-TSD as independent variables.*

Patient With				
TSD	ABL	Gender	Predicted Value	95% Estimation Limits
20	0	m	28	13–43
		f	26	13–40
30	0	m	29	14–44
		f	28	14–41
50	0	m	31	16–46
		f	30	16–44
60	1	m	38	24–53
		f	38	24–52
90	2	m	43	29–58
		f	43	29–57
120	3	m	47	32–62
		f	47	34–61
130	4	m	49	35–64
		f	50	36–64
130	5	m	51	36–66
		f	52	38–65

sqrt, square root; ABL, alveolar bone level; TSD, total score for each dentition; m, male; f, female.

greement, only one calibrated observer, who was trained by an experienced dentist, performed the collection of the findings in the current survey. To improve the intra-observer reproducibility and reduce the measurement errors, Willems et al. (41) used a stereomicroscope when assessing OPGs for dental age calculation. They found comparable age determinations when using a magnifying glass or a stereomicroscope. They also demonstrated that the experience of an examiner is the most important factor for obtaining accurate results in dental age determination. Kolltveit et al. (42) attempted to enhance the reliability of measurements on the dental radiographs by using a computer-assisted method, but his results demonstrated the superiority of the manual method. However, it must be considered that the computer systems and software are developing rapidly, so that in the near future more effective systems for radiological assessment may be available.

Both ABLs and developmental stages of the root formation of the third molars are findings that have been associated with age in the literature (10,11,21,23,43). However, the subjects in the present study were older than 20 years and the root formation at the third molar was completed in most of the cases. Therefore, ABL as a periodontal finding, but not the developmental stages of the root formation of the third molars, was determined on the radiographs. In the current study, the ABL showed the highest correlation with the chronological age. But even the improved Pearson's correlation coefficient of 0.756 for sqrt-ABL was not sufficient for age determination. Benn (44) demonstrated that the decrease in ABL occurs very slowly, and he calculated a detectable alveolar bone loss of 0.7–1.9 mm per year depending on the monitoring system. Albandar et al. (43) showed in a large population consisting of individuals aged 30–80 years an increase in the prevalence and extent of the damages in periodontal tissues with age. In addition, he demonstrated a strong correlation between the ABL and genetic and environmental factors, previous periodontal status as well as the tooth type (43,45). Horning et al. (46) also found that an age greater than 30 years is a risk indicator for periodontitis, but they also demonstrated a strong association with smoking and racial background. Their findings confirm the relation between the ABL and the chronological age of the patients found in the present study, but they also refer to additional risk factors, which can affect changes in periodontal tissues like the alveolar bone. The disregard of these risk factors in the current study might be the reason for the inaccuracy of age assessment using the ABL alone. In the present study, to minimize the cultural and racial differences, mostly persons of middle European origin were included. However, factors like smoking or early periodontal conditions should additionally be taken into account in further studies.

As a clinical finding, the DMFT index representing the caries prevalence in a dentition was used in the current survey. Friedrich et al. (47) studied the possibility to use caries and fillings in third molars to determine whether the subject is of age (18 years). They found a very high correlation between the fillings in wisdom teeth and age above 18 years; however, the majority of the wisdom teeth showed neither caries nor fillings. Hannigan et al. (48) showed for similar tooth surfaces in the same position in the opposite sides of the mouth comparable time intervals till the first detectable demineralization occurred after eruption (survival times). They calculated median survival times of 3.9–62.3 years for different tooth surfaces so that a relation of age to the dental decay in a population with detectable caries could be achieved. In the present study, the patients had a mean age of 37 years and for most of the teeth and tooth surfaces the reported median survival times after eruption were already exceeded. Although a good correlation between age and DMF-T was determined in this study, the regression coefficients showed that an age assessment using only DMF-T values was not accurate. Additionally, the clinical and radiological findings were combined, and used for further analysis. The presence and area of dental decay, presence of dental fillings, crowns, secondary caries, and apical pathological changes were ranked according to their occurrence. The scores for each tooth were added up and a TSD, was calculated. Although the TSD showed a better correlation with the chronological age than the DMF-T index, the single use of TSD did not allow accurate age determination, either. Both variables, DMF-T and TSD, are interrelated with oral hygiene and dietary habits as well as with life events (48,49). These variables may therefore only be useful for age determination in a homogenous group or if habits and life events are well documented.

Dental attrition is another clinical finding that can be used for age assessment (12,14). But Santini et al. (9) showed attrition to be an inaccurate method using a simple ordinal score. In a later study using the average state of attrition (ASA) method in an Indian population for age determination, Ajmal et al. (17) found discrepancies of 6–11 years. This parameter was not included in the present study because of the strong association of attrition with bruxism, diet, environment, and medication (50).

The present study verified a possible improvement of dental age determination by combining different parameters that univariately showed a correlation with chronological age. The regression analyses demonstrated that the use of a single parameter alone or in combinations with other parameters was insufficient for accurate age determination. The combination of sqrt-TSD and sqrt-ABL, which showed the best goodness of fit (r^2), was used for creating models for age determination with corresponding 95% estimation limits. However, exemplary age determination using this model lead to discrepancies of $\pm$ 15 years.

The current study showed that clinical and radiological findings, which can be collected without special knowledge of forensic sciences, could not be used for accurate age determination as a single method. Based on their findings, the authors of the present study strongly suggest that this method can only be used to support other methods of age estimation. Further studies, including additional clinical and radiological variables such as dental attrition and secondary dentin formation, but also environmental factors, such as smoking, could lead to better results.

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