Modified Gustafson's Method for Age Estimation from Premolars: A Study Employing Dental Panoramic Tomographs

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Abstract

Age estimation plays an important role in forensic medicine, clinical dentistry and archaeology for the identification process. The age estimation becomes complex in adults when the mineralization process of all the teeth has completed.

The objective of this study was to estimate the age of Malaysian adults by using Gustafson's method observed on the dental panoramic tomographs from mandibular premolars.

Four hundred dental panoramic tomographs of 227 female and 173 male Malaysians aged between 18 and 74 years old were reviewed. The characteristics of secondary dentin formation, cementum apposition, periodontal recession and attrition were evaluated in all the mandibular premolars.

There was a significant difference between right and left mandibular premolars using the paired t test ($p<0.05$). The linear correlation of the individual characteristics with the chronological age of each premolar was examined. The multiple regression analysis was done for the equation of age estimation. The R values amounted between 0.77 and 0.79 with the mandibular left second premolar having the highest value.

The method devised by Gustafson can therefore be used for forensic age estimation for the Malaysian population as it is considered as a less invasive method.

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Introduction

Age estimation has an important role in the identification of an individual. Teeth and associated dental restoration (s) are one of the most frequently used methods for positive identification of an unknown body as its resist's destruction and decomposition. The forensic dentist usually serves as part of the identification team with the coroner or a medical examiner in the identification process.[1,2] The services of an anthropologist can also be sought in determining age, race and sex of badly decomposed or skeletonization bodies. However, in the case of an adult, the determination of the age becomes more difficult due to the completion of tooth development. It is even reported that the degree of accuracy was less for age estimation of young adults, based upon the closure of the root apices and the eruption of the third molars.[3–5]

In children and adolescents, age estimations are based on the developmental stage of the deciduous and permanent dentition. Most of these are based on a comparison of the radiographic development of teeth with standard diagrams or charts collected from a large number of persons, usually in a well-defined geographic region.[6] With advancing age, secondary dentine is deposited within the wall of the dental pulp chamber, leading to a reduction in the size of the pulp cavity. Tooth wear which includes attrition, abrasion and erosion have also been widely used as a tool of age estimation.[2,3] These age-related changes can be evaluated employing dental

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radiographs.[4-9]

Several methods for the determination of dental development from radiographs have been described. [4-12] The dental radiographs have been used relatively recently for age estimation methods since they are very convenient, simple with no invasive procedures involved and therefore suitable for living subjects. [4-9]

Gustafson (1950) published one of the first techniques for age estimation on teeth. [3] In this method, the age of an adult individual was assessed from a tooth or teeth, using a multifactorial point system. Six retrogressive or degenerative changes in teeth were examined, namely attrition, secondary dentin deposition, periodontal status, root transparency, cementum apposition and root resorption.[3] In 1982, researchers reported that the characteristics studied by Gustafson (except apical translucency) can also be determined using dental films.[4] Subsequently, multiple studies have been conducted with different dental radiographic techniques employing the characteristics studied by Gustafson. In 2012, Olze et al. have carried out an investigation to study the reliability of these characteristics employing dental panoramic tomography and reported favorable results. [5]

Mandibular premolar teeth were selected for this study as they are more resistant to destruction compared to incisors, while in terms of morphology they are monoradicular and having large pulpal areas.[5] It is easy to evaluate mandibular premolars teeth as they are free from cervical vertebrae projections on the dental panoramic image. Thus, the aim of this study was to assess whether the characteristics described by Gustafson, namely attrition, secondary dentine formation, cementum apposition and periodontal recession can be used appropriately for forensic age estimation of adult Malaysians.

Materials and methods

Four hundred dental panoramic tomographs (DPTs) were collected retrospectively from Faculty of Dentistry, Universiti Sains Islam Malaysia (USIM) and Oral health Centre, SEGI University, Malaysia. The DPTs were collected from the year 2013 to 2018. The records belonged to Malaysians, who were either from the Malay or Chinese ethnicities. There were 173 males and 227 females, aged from 18 years to 74 years old. The DPTs were then stratified in age groups. All DPTs were taken following the standardized protocol for patient positioning and exposure parameter settings (120 kVp, 3-7 mA and 20 second). The investigation described herein was approved by both USIM and SEGI University institutional Research Ethics Committees (USIM: 2.20/122/1 Jld. 83) and (SEGi/EC/2017-2018/FOD/S-05)

The mandibular premolars were evaluated regarding secondary dentin formation, periodontal recession, attrition and cementum apposition. The exclusion criteria were premolars with caries, crowned tooth or bridge abutment, restored tooth, post and core restoration, root filled, infected tooth, impacted tooth, tooth with apicectomy and patients with unknown chronological age. Poor-quality DPTs and the absence of all mandibular premolars were also excluded from the sample.

The intra-observer and inter-observer reliability were done on 20 DPTs. Thus, Cohen's kappa coefficient was used for intra- and inter-observer agreement calculations. The paired t test was done to compare right and left mandibular premolars.

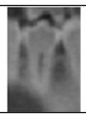
Stage	Description	DPT	Schematics diagram
Stage 0	Pulp horn reaches to above crown equator*		
Stage1	Pulp horn reaches maximum to crown equator		
Stage 2	Pulp horn exceeds enamel-cementum boundary and falls short of crown equator		
Stage 3	Pulp horn reaches maximum to enamel-cementum boundary		

Table 1. The stage of secondary dentin formation.
*Crown equator refers to the mid-point of crown length measured from cervical line to the highest cusp tip (Koh et al., 2017).

The correlation between chronological age and the individual degenerative characteristic said above was examined by means of linear and multiple regression analyses. The chronological age formed the dependent variable, and those degenerative characteristics formed independent variable. The

following stage classification was used for the characteristics of secondary dentin formation (Table 1), periodontal recession (Table 2), attrition (Table 3) and cementum apposition (Table 4). [5,7,8,9] Validation test using multiple linear regression equations was done using set of samples.

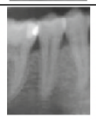
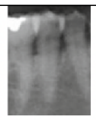
Stage	Description	DPT	Schematics Diagram
Stage 0	No periodontal recession		
Stage 1	Periodontal recession into cervical root third		
Stage 2	Periodontal recession into middle root third		
Stage 3	Periodontal recession into apical root third		

Table 2. The stage of periodontal recession.

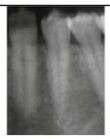
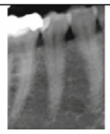
Stage	Description	DPT	Schematics diagram
Stage 0	No attrition, cusp tip present		
Stage 1	Beginning of attrition with loss of cusp tips		
Stage 2	Attrition reaching into dentin		
Stage 3	Attrition reaching into dentin with opening of pulp cavity		

Table 3. The stage of attrition.

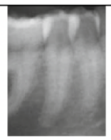
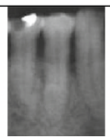
Stage	Description	DPT	Schematics
Stage 0	No visible cementum apposition		
Stage 1	Beginning of apical cementum apposition		
Stage 2	Clearly visible cementum apposition, reaching beyond the apex		

Table 4. The stage of cementum apposition.

Results

Intra-observer and inter-observer error

The statistical analyses performed showed that there were no differences between intra-observer and inter-observer measurements in the 20 selected DPTs. The results for the level of agreement were considered good as the kappa value was between 0.61 -0.80 (Table 5).

Observer	Kappa Value	Level of Agreement
Inter-observer	0.71	Good
Intra-observer	0.77	Good

Table 5. The agreement values for Inter and Intra observer error as raw data.

Bilateral measurement of mandibular premolars

Paired t-test was done to evaluate the mean values of each variable in the same subject. In this study, the difference for the mean of right and left mandibular premolars measurements were analyzed. The results on the eight pairs studied revealed from that there was a significant difference between right and left premolar teeth on characteristics of secondary dentin (first premolars), cementum apposition (first and second premolars) and periodontal recession (second premolars) ($p<0.05$) (Table 6).

Pairs		Mean	Standard Deviation (SD)	Standard Error Mean (SEM)	p-value
Pair 1	MRFPSD	1.79	0.615	0.031	0.04*
	MLFPSD	1.85	0.545	0.027	
Pair 2	MRFPPR	0.66	0.675	0.034	0.15
	MLFPPR	0.69	0.643	0.032	
Pair 3	MRFPA	0.33	0.485	0.024	0.43
	MLFPA	0.31	0.488	0.024	
Pair 4	MRFPCA	0.29	0.453	0.023	0.03*
	MLFPCA	0.33	0.477	0.024	
Pair 5	MRSPSD	2.00	0.456	0.023	0.12
	MLSPSD	2.04	0.479	0.024	
Pair 6	MRSPPR	0.77	0.652	0.033	0.01*
	MLSPPR	0.91	0.678	0.034	
Pair 7	MRSPA	0.40	0.510	0.025	0.48
	MLSPA	0.38	0.501	0.025	
Pair 8	MRSPCA	0.16	0.369	0.018	0.01*
	MLSPCA	0.23	0.420	0.021	

Table 6. The mean (SD and SEM), and p value of right and left mandibular premolars.
*p<0.05, Significant difference.
MRFPSD: Mandibular Right First Premolar Secondary Dentin, **MRFPPR**: Mandibular Right First Premolar Periodontal Recession, **MRFPA;** Mandibular Right First Premolar Attrition, **MRFPCA:** Mandibular Right First Premolar Cementum Apposition, **MRSPSD**: Mandibular Right Second Premolar Secondary Dentin, **MRSPPR**: Mandibular Right Second Premolar Periodontal Recession, **MRSPA**: Mandibular Right Second Premolar Attrition, **MRSPCA**: Mandibular Right Second Premolar Cementum Apposition, **MLFPSD**: Mandibular Left First Premolar Secondary Dentin, **MLFPPR**: Mandibular Left First Premolar Periodontal Recession, **MLFPA;** Mandibular Left First Premolar Attrition, **MLFPCA:** Mandibular Left First Premolar Cementum Apposition, **MLSPSD**: Mandibular Left Second Premolar Secondary Dentin, **MLSPPR**: Mandibular Left Second Premolar Periodontal Recession, **MLSPA**: Mandibular Left Second Premolar Attrition, **MLSPCA**: Mandibular Left Second Premolar Cementum Apposition.

Similarity of measurements of males and females

An attempt was made to determine whether the values for male and female were significantly different. Independent t-test were performed, and the results are given in Table 7. Interestingly, out of the 16 Gustafson's characteristics (4 mandibular premolars), only 4 characteristics showed significant difference in values (p<0.05).

Simple linear regression equation

Simple linear regression equations were used when one independent variable was utilized to estimate the value of one dependent variable. The simple linear regression equations for each biological characteristic were presented along with values of the correlation coefficient (R), coefficients of determination (R2) and standard error of estimate (SEE) values for each mandibular premolar tooth. The correlation coefficient (R) represented the correlation between each parameter and age estimation. Positive value shows that each parameter has a positive relationship between the parameter and age estimation. Increased values in the score of the parameter indicated an increase in age estimation. Furthermore, the coefficient of determination (R^2) showed how well the statistical data fitted into the regression line. Meanwhile, the SEE measures the accuracy of the estimates made by the regression line. Small value of SEE indicated good accuracy of predictions of age estimation generated by the equations (Table 8-11).

NO	PARAMETER	SEX	MEAN	STANDARD DEVIATION	SEM	p-value
1	MRFPSD	MALE	1.83	0.648	0.049	0.209
		FEMALE	1.75	0.588	0.039	
2	MRFPPR	MALE	0.76	0.679	0.052	0.008*
		FEMALE	0.58	0.669	0.044	
3	MRFPA	MALE	0.38	0.522	0.04	0.046
		FEMALE	0.28	0.451	0.03	
4	MRFPCA	MALE	0.29	0.457	0.035	0.779
		FEMALE	0.28	0.451	0.03	
5	MRSPSD	MALE	1.99	0.488	0.037	0.756
		FEMALE	2.01	0.431	0.029	
6	MRSPPR	MALE	0.82	0.653	0.05	0.154
		FEMALE	0.73	0.649	0.043	
7	MRSPA	MALE	0.46	0.534	0.041	0.022*
		FEMALE	0.34	0.485	0.032	
8	MRSPCA	MALE	0.13	0.341	0.026	0.155
		FEMALE	0.19	0.389	0.026	
9	MLFPSD	MALE	1.89	0.565	0.043	0.152
		FEMALE	1.81	0.527	0.035	
10	MLFPPR	MALE	0.81	0.659	0.05	0.002*
		FEMALE	0.6	0.618	0.041	
11	MLFPA	MALE	0.36	0.527	0.04	0.075
		FEMALE	0.27	0.454	0.03	
12	MLFPCA	MALE	0.34	0.475	0.036	0.755
		FEMALE	0.33	0.479	0.032	
13	MLSPSD	MALE	2.12	0.485	0.037	0.003*
		FEMALE	1.98	0.465	0.031	
14	MLSPPR	MALE	0.98	0.711	0.054	0.056
		FEMALE	0.85	0.648	0.043	
15	MLSPA	MALE	0.43	0.519	0.039	0.099
		FEMALE	0.34	0.485	0.032	
16	MLSPCA	MALE	0.24	0.43	0.033	0.528
		FEMALE	0.22	0.412	0.027	

Table 7. Independent t test between male and female, *p<0.05, significantly different.
MRFPSD: Mandibular Right First Premolar Secondary Dentin, **MRFPPR**: Mandibular Right First Premolar Periodontal Recession,

MRFPA; Mandibular Right First Premolar Attrition, **MRFPCA:** Mandibular Right First Premolar Cementum Apposition, **MRSPSD**: Mandibular Right Second Premolar Secondary Dentin, **MRSPPR**: Mandibular Right Second Premolar Periodontal Recession, **MRSPA**: Mandibular Right Second Premolar Attrition, **MRSPCA**: Mandibular Right Second Premolar Cementum Apposition, **MLFPSD**: Mandibular Left First Premolar Secondary Dentin, **MLFPPR**: Mandibular Left First Premolar Periodontal Recession, **MLFPA;** Mandibular Left First Premolar Attrition, **MLFPCA:** Mandibular Left First Premolar Cementum Apposition, **MLSPSD**: Mandibular Left Second Premolar Secondary Dentin, **MLSPPR**: Mandibular Left Second Premolar Periodontal Recession, **MLSPA**: Mandibular Left Second Premolar Attrition, **MLSPCA**: Mandibular Left Second Premolar Cementum Apposition.

Characteristics	Formula	R	R^2	SEE
Secondary Dentin	Age = 0.25 + 0.84 x SD	0.48	0.23	0.94
Periodontal Recession	Age = 1.10 + 0.99 x PR	0.62	0.39	0.84
Attrition	Age = 1.30 + 1.40 x A	0.63	0.40	0.83
Cementum Apposition	Age = 1.45 + 1.07 x CA	0.45	0.20	0.96

Table 8. Simple linear regression equation for mandibular right first premolar (28).

Characteristics	Formula	R	R^2	SEE
Secondary Dentin	Age =1.05SD – 0.35	0.45	0.20	0.96
Periodontal Recession	Age =1.00 + 0.98PR	0.60	0.36	0.86
Attrition	Age = 1.27 + 1.22A	0.58	0.34	0.88
Cementum Apposition	Age = 1.50 + 1.55A	0.53	0.28	0.91

Table 9. Simple linear regression equation for mandibular right second premolar (29).

Characteristics	Formula	R	R^2	SEE
Secondary Dentin	Age = 0.09 + 0.90 x SD	0.46	0.21	0.95
Periodontal Recession	Age = 1.02 + 1.06x PR	0.64	0.50	0.83
Attrition	Age = 1.33 + 1.37 x A	0.62	0.39	0.84
Cementum Apposition	Age = 1.50 + 1.04 x CA	0.46	0.21	0.95

Table 10. Simple linear regression equation for mandibular left first premolar (21).

Characteristics	Formula	R	R^2	SEE
Secondary Dentin	Age = 1.07 x SD – 0.44	0.48	0.23	0.94
Periodontal Recession	Age = 0.87 + 0.97 x PR	0.61	0.38	0.85
Attrition	Age = 1.24 + 1.34 x A	0.63	0.39	0.84
Cementum Apposition	Age = 1.42 + 1.47 x CA	0.58	0.33	0.88

Table 11. Simple linear regression equation for mandibular left second premolar (20).

Multiple linear regression equations

Multiple linear regression equations were applied when more than one independent variable was utilized to estimate the value of a dependent variable. Table 12 shows the new model for multiple linear regressions that was obtained by combining the degenerative parameters studied.

Tooth	Formula	R	R^2	SEE
21 (Mandibular left first premolar)	Age = 0.42 + 0.30 x SD + 0.61 x PR + 0.77 x A + 0.36 x CA	0.77	0.60	0.68
20 (Mandibular left second premolar)	Age = 0.27 + 0.30 x SD + 0.49 x PR + 0.66 x A + 0.75 x CA	0.79	0.62	0.67
28 (Mandibular right first premolar)	Age = 0.66 + 0.18 x SD + 0.56 x PR + 0.81 x A + 0.40 x CA	0.77	0.59	0.69
29 (Mandibular right second premolar)	Age = 0.13 + 0.42 x SD + 0.53 x PR + 0.59 x A + 0.90 x CA	0.77	0.60	0.69

Table 12. Multiple linear regression equation for mandibular premolars with parameters of secondary dentin, periodontal recession, attrition and cementum apposition.

Tooth	Mean	SD	SEM	P value
21 (Mandibular left first premolar)	-0.123	0.714	0.160	0.450
20 (Mandibular left second premolar)	-0.004	0.710	0.159	0.980
28 (Mandibular right first premolar)	-0.135	0.772	0.173	0.444
29 (Mandibular right second premolar)	-0.168	0.976	0.218	0.452

Table 13. Paired t test analysis between actual chronological age and age estimation using multiple regression equation.
*SD = standard deviation, SEM = standard error of the mean. p>0.05, no significant difference.

Validation test using multiple linear regression equations against set of samples. Validation test was done to test the accuracy of the regression equations yielded in this study. The equations were evaluated against 20 randomly selected DPT samples. The correspondence were evaluated by applying the equations that were generated. Paired sample t-test was employed to compare the means between actual chronological age and estimated

age of these samples. Table 13 shows that there was no difference between the actual chronological age and estimated age of these 20 samples (p>0.05).

Year	Author	Method of Radiology	Sample Population	R	R2	SEE
2012	Olze et al.	DPT	Germany (15 – 40 yrs)	0.65 - 0.73	0.43 - 0.53	5.3 – 5.7
2016	Timme et al.	DPT	Germany (15 – 40 yrs)	0.69 - 0.77	0.47- 0.59	4.6 – 5.2
2017	Lavez et al.	DPT	Brazilian (20 – 70 yrs)	0.65 – 0.73	0.43 - 0.53	5.3 – 5.7
2017	Koh et al.	CBCT	Malaysian (20 – above 60 yrs)	0.44 and 0.48*	0.20 and 0.23*	12.12 and 12.46*
				0.85 and 0.82**	0.72 and 0.68**	7.47 and 7.16**
2018	Present study	DPT	Malaysian (18–above 60 yrs)	0.77 – 0.79	0.59 – 0.62	0.67 – 0.69

Table 14. Comparison of age estimation employing Gustafson's method in different populations in the world.
*Value of characteristics studied: attrition + secondary dentin formation + periodontal recession, left and right first mandibular premolar.
**Value of parameter studied: buccal bone level only, left and right first mandibular premolar.

Discussion

Gustafson was one of the earliest researchers, who reported that there were structural/biological degenerative changes in the teeth that were related to chronological age.[3] Subsequently, this was followed by several studies, and it was proven that this method can be used for age estimation of adults as the last third molar is completely developed at early adulthood.[4,5,7-9] Subsequently, structural changes start immediately after a tooth has erupted and continues throughout the whole life. Interestingly, this method which indicated six regressive biological changes has been modified and evaluated in several studies of extracted teeth as well as radiographs.[3-5,7-9]

Kvaal et al. in 1995 discovered correlations between ratios of height and width of teeth with pulp cavities on dental radiographs to determine the age.[12] However, Olze et al. in 2012 adopted the Gustafson's characteristics on DPTs as a better method for age correlation.[5] They used lower premolars, and their findings were used to develop a favorable formula. As their research had a limited age span, they recommended the formula for age estimation of only young adults, especially those aged from 15 to 40 years old. In addition, their study only evaluated four biological changes (secondary dentin formation, periodontal recession, attrition and cementum apposition) as the other characteristics were not clearly observed on the radiographs. [4,5]

At the beginning of the preliminary study, 20 DPT images were selected and evaluated for intra and inter-observer reliability. The Kappa result was considered substantial (0.77 for intra-observer and 0.71 for inter-observer reliability).

Significant differences in the results were obtained when paired t-test was done to evaluate the mean values of each Gustafson's degenerative characteristics of right and left mandibular premolars. However, it was noticed that there was no significant difference between the male and female, except for a few characteristics. These include the periodontal recession for right and left first mandibular premolar, attrition for right first and second premolar and secondary dentin formation for left second premolar. Therefore, it can be safely stated there would not be much difference in the estimated age values when gender is ignored in actual age estimation.

The results of the multiple regression formula obtained from the four Gustafson's degenerative characteristics for all the premolars were highly correlated with chronological age as the values of the correlation coefficient, R, ranged from 0.77 to 0.79 (Table 14). These values were slightly higher than Olze et al. (R value ranged from 0.65 to 0.73), although their sample size was much higher (1299 Germans). [5] Again Timme et al. in 2016 reported the R values amounted to 0.69 – 0.77 in a similar German cohort study.[7] Subsequently, Lavez et al. found the value of correlation between chronological age and the Gustafson's characteristics using the multiple regression analysis was lesser R: 0.65 to 0.73.[8] Meanwhile, Koh et al. in 2017 also did the similar study on Malaysians using Cone-Beam Computed Tomography (CBCT) scans (centermost slice of the premolar tooth) to observe structural changes. They found the R values for the three Gustafson criteria were only 0.44 (left) and 0.48 (right). However, their study on another age-related change, namely, the buccal bone level, the value obtained was high; 0.82 (right) and 0.85 (left).[9]

It must be stated here that the regression equations calculated when combining selected Gustafson's degenerative changes can be recommended only in certain situations (Table 8 -

11). The R value for attrition and periodontal recession alone was always higher compared to the other Gustafson's characteristics for the premolars (right and left side). Moreover, the mandibular left second premolar showed the highest correlation in the multiple regression analysis and therefore this tooth must be the preferred tooth of choice in age estimation (Table 12). Nevertheless, it should be borne in mind that the quality of X- ray images is very crucial to get greater accuracy for the assessment of the structural changes noticed on the teeth and the periodontium. Additionally, we would expect that changes of the Gustafson's characteristics should be bilaterally similar for the premolars as they have similar timing and sequence of development, but this was surprisingly not evident in this study.

As stated earlier, the assessment of age using permanent dentition becomes limited when the third molars have erupted into the oral cavity, usually by 17-21 years of age. This method of using Gustafson's characteristics on DPTs is relatively easy and can be developed for other racial groups. It may also be used along with those who have or are doing adult age estimation based of pulpal cavity to tooth ratio from CBCT scans enhanced with Mimics software.[17] These methods will definitely provide an excellent dental age estimation of the Malaysian population.

Conclusions

In conclusion, results from this study shows that the four characteristics (secondary dentin formation, periodontal recession, attrition and cementum apposition) when used collectively for the Gustafson's (or Ozle's) method, has a strong correlation with chronological age for forensic age estimation. This study will, therefore, enhance the human identification process of unknown deceased persons. Moreover, using population-specific data in age estimation is recommended to guarantee for optimal feasibility and reproducibility of the evaluation. In addition, this research may be useful for validation and comparison with other similar populations having Mongoloid ancestry in Asia.

Declaration of Interest

The authors have no relevant conflicts of interest to declare.

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