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Estimation of Age from Individual Adult Teeth

When one must identify a deceased individual, accurate estimation of the age of the individual is important. Teeth are particularly useful in age evaluations because they display a number of observable age-related variables and they tend to remain intact under circumstances which might alter or obliterate the rest of the skeleton. Where dental records are available, of course, separate determination of age may not be necessary, but when little or no information is available about the deceased individual, a simple estimation of age is of great value.

There is nothing novel about using teeth to estimate age. As long ago as 1890, W. D. Miller [*1*] discussed the histological changes in the dentin in response to age and wear. The numerous methods for age determination from teeth are discussed thoroughly in Refs *2* and *3*.

Basically, age-related changes in the dentition can be divided into three categories: formative, degenerative, and histological. The formative, or developmental, changes are good predictors of age in the earlier years, at least until age 12. Formative changes are subdivided into the following stages: the beginning of mineralization, the completion of the crown, the eruption of the crown into the oral cavity, and the completion of the root. A number of investigators have established age values for each of these developmental changes.

Degenerative changes also provide age data. The obvious degenerative changes in adult dentition are color change, attrition, and periodontal attachment level. Color change is highly variable and is closely related to diet and oral hygiene.

Attrition (Fig. 1) is the degree to which the enamel, and subsequently the dentin, is worn away on the occlusal surfaces of the teeth. Attrition is the result of frictional wear and is a natural age-related phenomenon. Abrasion is the pathological and unusual condition in which the tooth surfaces are rapidly worn away by strongly abrasive food, by bruxism (tooth grinding), or by culturally related behavior, such as leather chewing or tooth filing [*4,5*]. Most investigators such as Gustafson [2] equate attrition with abrasion in their evaluations.

Periodontal attachment level (occasionally called paradentosis) is also an age-related factor. The level of attachment of the gingival tissues tends to recede with advancing years. Periodontal disease or abrasion of gingival tissue may, of course, distort the measurement of this variable.

Internal tooth changes include the deposition of secondary dentin, cementum apposi-

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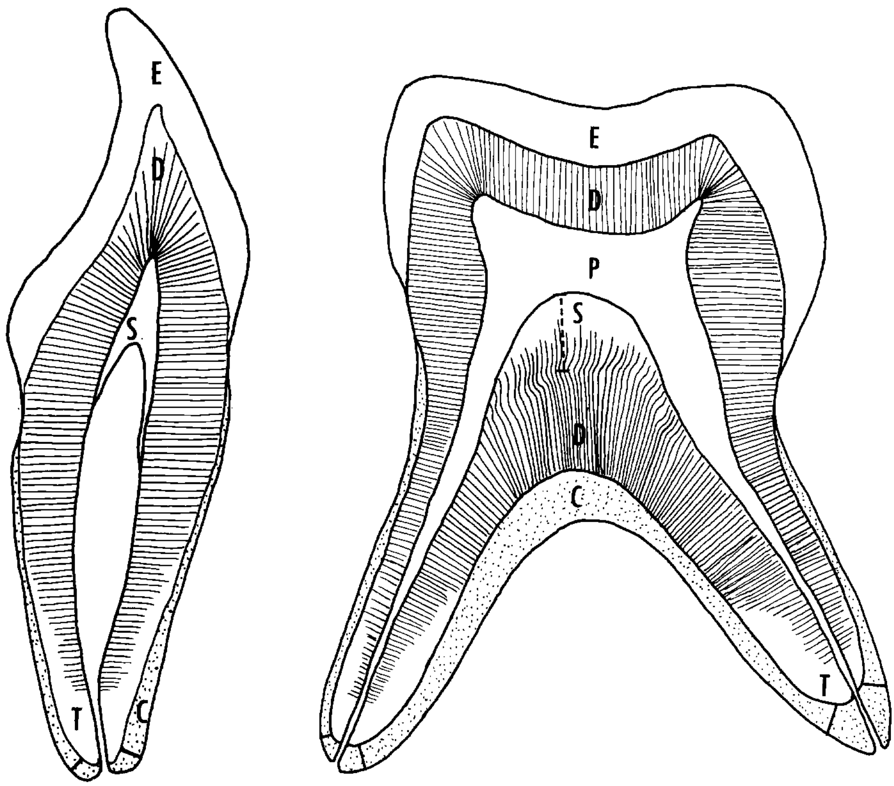

FIG. 1—*Sagittal section drawings of an incisor and a molar.* E = *enamel;* D = *primary dentin;* S = *secondary dentin;* T = *transparency; and* C = *cementum apposition. The measurement position for molar secondary dentin is indicated by a dotted line. The measurement positions for cementum apposition are indicated by a solid line.*

tion, root resorption, and root translucency (also called transparency). Secondary dentin is the calcified nontubular substance deposited by the pulp on the walls of the pulp chamber and root canal. Deposition of secondary dentin causes a decrease in the size of the pulp chamber (Fig. 2). Worn and unworn teeth from the same mouth tend to show the same amount of secondary dentin [*6*]. Philippas [*7-9*] carried out very thorough studies on secondary dentin formation as well as transparency. He concluded that age has a greater effect than pathology in secondary dentin formation.

Cementum is the mineralized tissue which covers the tooth root. It secures the periodontal fibers to the root surface. Layers of cementum are laid down throughout life in the process of continually reanchoring the teeth. Zander and Hurzeler [*10*] developed a technique to quantitatively measure cementum apposition. They demonstrated a straight-line relationship between age and cementum thickness. "The thickness of cementum was approximately tripled between ages of 11 and 76 years. This rate was not the same for every area of the root. It was less near the cemento-enamel junction and more in the apical area" [*10*].

Root resorption is also considered to be an age-related phenomenon. Orban [*11*], however, states that "cementum is not resorbed under normal conditions." It should be noted that normal conditions are sometimes difficult to define. Resorption usually begins at the root tip and progresses through the cementum and into the dentin.

Transparency or translucency in the root is caused by the increased mineralization of the dentinal tubules with advancing age. Mineralization associated with age begins at the

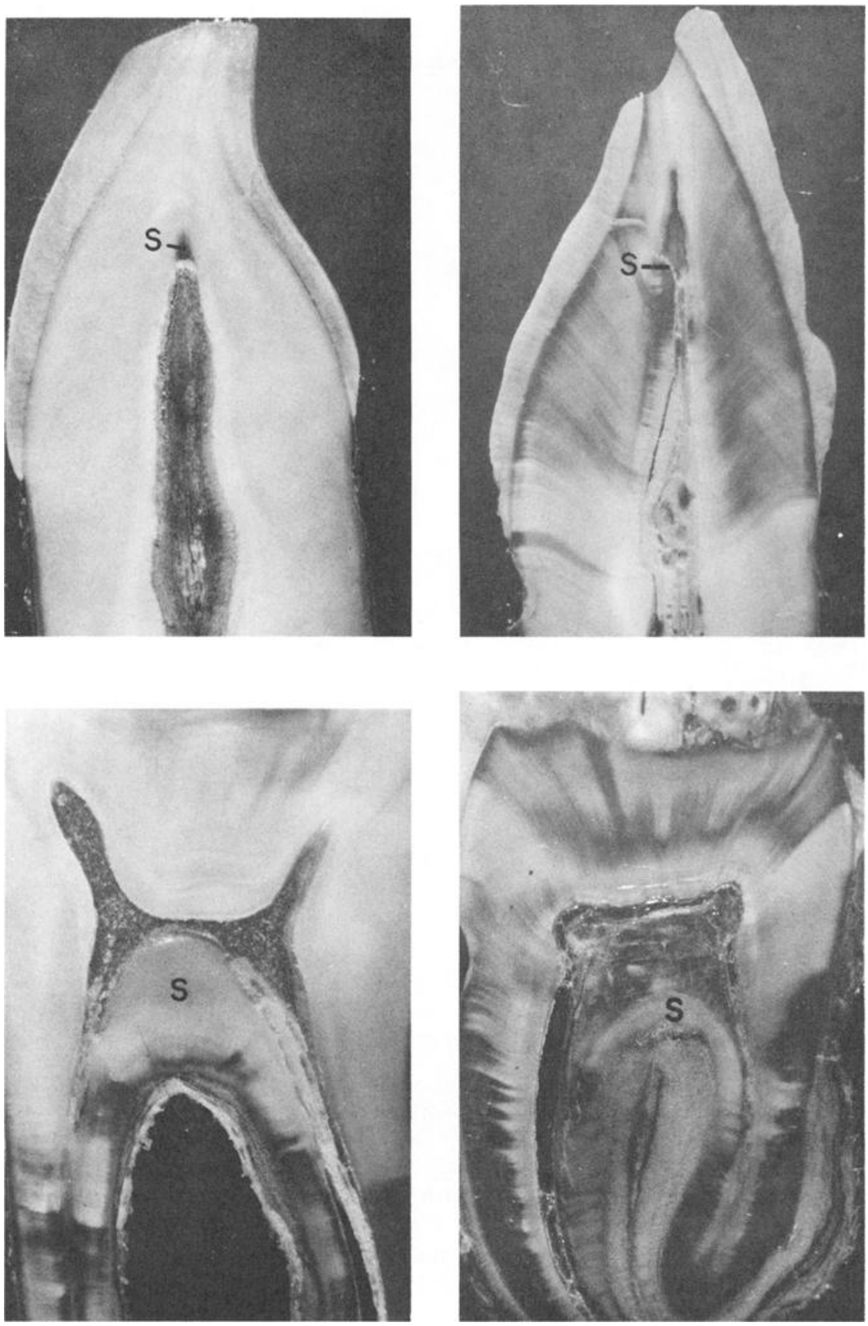

FIG. 2—*Development of secondary dentin within the pulp chamber. The secondary dentin appears translucent, for the most part.* (upper left) *Incisor #106; donor, 35 years old.* (upper right) *Incisor #378; donor, 61 years old.* (lower left) *Molar #257; donor, 19 years old.* (lower right) *Molar #180; donor, 52 years old.*

root tip and proceeds toward the crown. The denser (more mineralized) portions of the tooth appear translucent in transmitted light. Beust [*12*] referred to such translucency as "dental sclerosis." Lamendin [*13*] studied root transparency in relation to age and concluded that the development of translucency is generally related to the age variation of the individual. He warned, however, that many other parameters can be involved in the phenomena of translucency which do not appear to be interrelated in any consistent manner.

Gustafson [*2,14*] developed a seminumerical method of age determination using six of the dental changes described above: attrition, paradentosis, secondary dentin, cementum apposition, resorption, and transparency (Fig. 3). Each variable as seen in a single

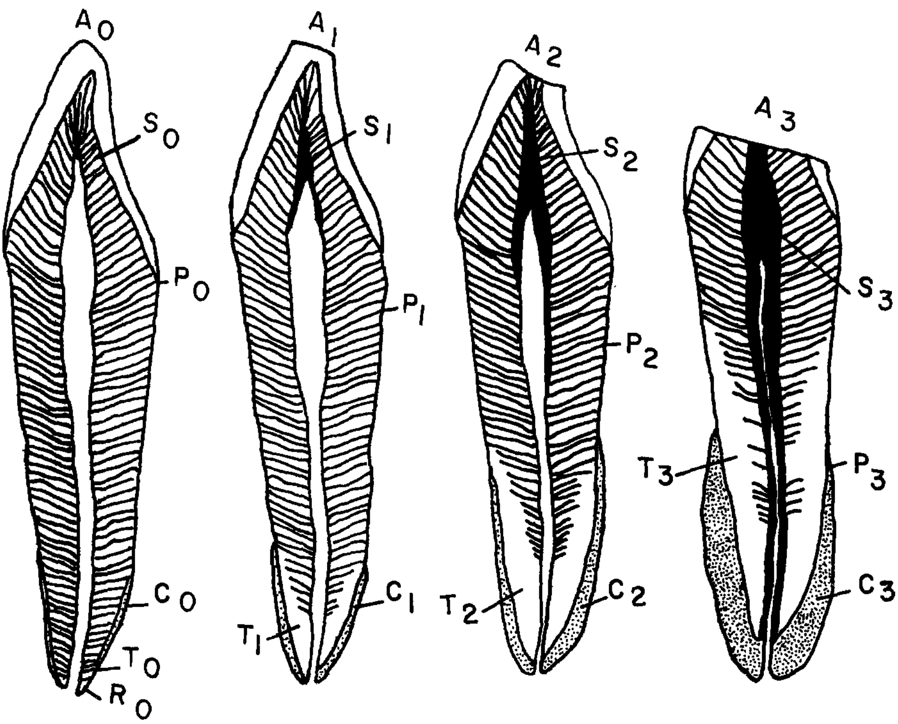

FIG. 3—*The Gustafson method, reproduced from Ref* 2. *"Six changes seen in ground sections of teeth become accentuated with age. The changes are here classified according to development. This sketch is used for later characterization and calculation of point values. The changes are:* A = *attrition;* S = *secondary dentine;* P = *changes in the paradentium;* C = *cementum apposition;* T = *transparency; and* R = *resorption (not indicated in sketch)"* [2].

longitudinal section of a tooth was evaluated on a scale of 0 to 3, using 0.5 whenever necessary in borderline evaluations. Gustafson then plotted the sum of the point values for each individual. The regression line obtained from the graph provided the basis for age estimation of other teeth. According to Gustafson, "the method has a high degree of accuracy" [*14*]. Actually, Gustafson was able to predict age within 3 years in up to 38% of his cases. The regression coefficient for his data was 4.56 ± 0.16, and the correlation coefficient was 0.98 ± 0.01.

Gustafson's method has been tested and modified by other investigators. Nalbandian and Sognnaes [*15*] precisely followed Gustafson's techniques, Miles [*16*] used a more intuitive method, and Johnson [*17*] used only relative area of root transparency. These attempts met with varying degrees of success, but none were able to equal or better the accuracy of Gustafson using his own technique.

The objectives of this study were to test again the Gustafson method of age determination by using a sample population from Jacksonville, Florida, and to try to improve the Gustafson method by weighing such variables as tooth position, race, sex, and periodontal disease.

It has been stated that some age-related variables are more reliable than others, and attempts have been made to use only the more reliable variables in estimation of age [*10,15,16*]. Perhaps a more accurate method could be formulated by weighing all of the variables, rather than discarding any of them, and utilizing each variable in relation to its contribution to age assessment.

Gustafson stated that anterior teeth are more reliable indicators of age than posterior teeth [*2*]. This is probably because the Gustafson method does not take into account the average age of eruption of each tooth. The anterior teeth erupt within 4 years, whereas there is a 10 to 15-year time lapse between the eruption of the first and third molars. On the other hand, perhaps the molars are considered to be unreliable indicators of age because the single ground section of the Gustafson method does not allow for an accurate evaluation of the asymmetrical molar.

Steggerda and Hill [*18*] and Hunt and Gleiser [*19*] report slight racial differences in time of tooth eruption of permanent dentition among American blacks and American whites. Race could possibly be a useful variable to include when estimating age.

Sex also may provide useful information in age estimation. Gleiser and Hunt [*20*] and Garn et al [*21*] report that eruption is earlier in females. In fact, tooth development in general is slightly, but consistently, more advanced in females than in males.

Periodontal disease should also be considered in age determination. Periodontal disease is known to affect directly several age-related variables. Gingival recession increases and cementum apposition decreases as resorption is accelerated. The dentinal tubules, also, may become mineralized (that is, transparent) more rapidly and less uniformly. Poor oral hygiene, poor diet, and periodontal disease are closely related. Income level, therefore, may be related to the incidence of periodontal disease. Gustafson considered the effect of income and compared results of teeth sampled at a public dental clinic with those sampled at a private clinic. He found that "In badly cared for teeth, the point values tended to be higher than in well treated ones, so that the age could not be fairly estimated" [*14*]. He obtained an average error of 7.5 years from the public clinic compared with an error of 4 years from the private clinic.

Sample and Methods

For the following study, 355 sample teeth from 267 individuals were obtained from a dental clinic in Jacksonville, Florida: 33% were from white patients and 67%, from black patients; 40% were from males and 60%, from females. Age range for the sample was 10.1 to 90.6 years with a mean of 39.5 years and a medium of 36.4 years.

A randomized control sample of approximately 20% of the total sample was selected at the beginning of the study.

The following procedure was carried out to prepare each tooth for evaluation. The teeth were placed in 10% formalin immediately after extraction. Each tooth was then examined and evaluated for degree of gingival recession. The teeth were embedded separately in polyester resin and sectioned with a diamond blade on a serial sectioning saw. The resulting sections were about 300 μm thick. The sections were mounted serially on 3 by 1-in. (76 by 25-mm) glass slides.

Two methods of analysis were used: Gustafson's method and multiple regression analysis.

Gustafson's method, as described in the introduction, involves summing the six point values obtained for each and regressing the sum with age.

Gustafson's method was used for the anterior teeth from the working sample (Fig. 4). The regression coefficient (4.41) was comparable to that obtained by Gustafson (4.56) (Table 1). Predictive success, however, was low. Only 23% of the teeth could be predicted within 3 years of the actual age of the tooth donor. Predictive success improved slightly when the total working sample was used (28%), but declined when the regression coefficient from the total working sample was used on the control group (23%). The regression coefficient from the total sample was used instead of the coefficient from the anterior teeth because the control group was composed of both anterior and posterior teeth and reducing it to only anterior teeth would result in too small a sample for a meaningful analysis.

The multiple regression analysis involved adding several class variables and weighting each variable. Programs for multiple regression analysis were obtained from Ref *22*.

The additional variables of tooth position, race, sex, and periodontal disease were then included in the data and a full multiple regression was performed on the three subgroups—anterior teeth of the working sample, posterior teeth of the working sample (molars only, in this case), and the total working sample. A separate set of regression coefficients resulted from each analysis. The coefficient sets were identified by letter. Set A was applied to anterior teeth, set B to posterior teeth, and set C to the total working sample.

Correlation (Fig. 5) was higher than that obtained by using the Gustafson method and predictive success improved considerably, matching and exceeding the success of Gustafson. However, when the coefficients obtained from the total working sample were used to predict age for the control sample, predictive success declined to a level only slightly above that of the Gustafson method (29% within 3 years).

A step-wise multiple regression was performed to better determine which effects (the variables and their interactions) were strongest in predicting age. Any effect with an F value less than 2.0 was excluded. (The F value is a measure of the contribution of the effect to the overall formula.)

The B values, regression coefficients obtained from the step-wise analysis, were then used to develop the most concise formula possible with the highest predictive quality (set D).

The resulting formula was used to predict age for the working sample (35% within 3 years) and for the control sample (27% within 3 years).

A t test was performed to test for a significant difference between the predictions obtained for the working sample and the predictions obtained for the control sample with coefficient set C and coefficient set D. A t value of 2.36 at 50 degrees of freedom was obtained when the results of set C as applied to the working sample were compared with the results of set C applied to the control sample. A t value of 1.65 at 50 degrees of freedom was obtained when the results of set D as applied to the working sample were compared with the results of set D applied to the control sample. A t value of 2.36 indicates a difference at the 5% level (probably significant), whereas a t value of 1.65 indicates no significant difference between the results from the control sample and the results from the working sample. It follows that the single best fit regression formula from set D coefficients should provide a better fit than set C for the entire population from which the samples were obtained.

Discussion and Conclusions

Accurate determination of age from individual teeth depends on the development of a sound predictive method capable of allowing for the heterogeneity within the study

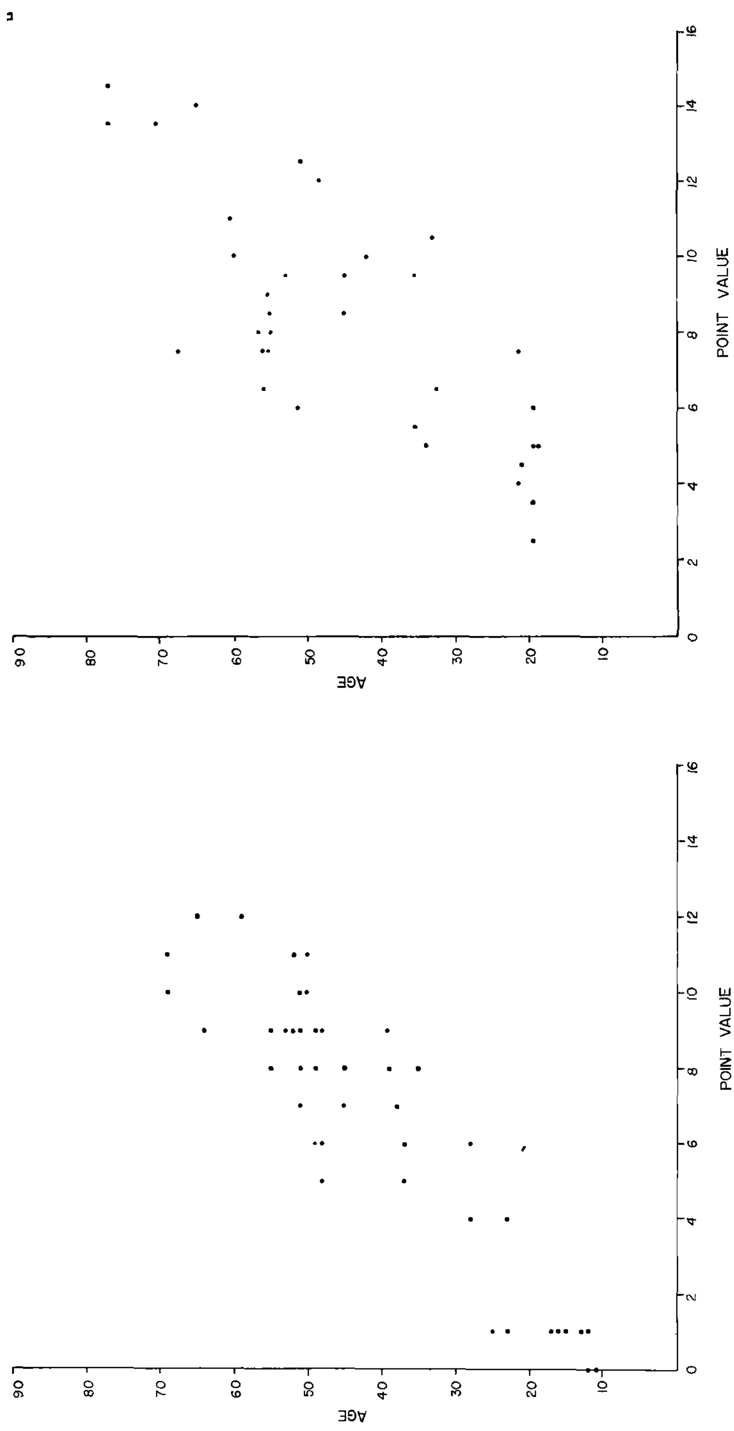

FIG. 4—*Comparison of Gustafson's sample* (left) *and the Jacksonville sample* (right). *Both sets of plotted values are from anterior teeth evaluated by the Gustafson method.*

TABLE 1—*Comparison of results from each sample subclass with each method of analysis.*

		Sample Size		Coefficients		Predictive Success, %		
Method of Analysis	Sample Subclass	Number	With Complete Data	Correlation, *r*	Regression	Within 3 years	Within 5 years	Within 10 years
Gustafson method	Gustafson's sample[a]	41	41	0.98	4.56	44	58	81
	anterior teeth, working sample	51	34	0.7563	4.41	23	29	56
	total working sample	281	168	0.8050	5.06	28	35	70
	control sample	68	51	...	5.06	23	39	70
Separate multiple regressions	anterior teeth, working sample	50	33	0.9960	set A[b]	93	100	...
	posterior teeth, working sample	175	95	0.9493	set B[b]	55	73	94
	total working sample	280	154	0.9336	set C[b]	42	60	84
	control sample	68	51	...	set C	29	39	67
Single best fit multiple regression	anterior teeth, working sample	50	40	0.9132	set D[b]	37	50	80
	posterior teeth, working sample	230	150	0.9132	set D	34	61	85
	total working sample	280	190	0.9132	set D	35	58	84
	control sample	68	51	...	set D	27	41	63

[a] Gustafson's results are from Table 5 of Ref *14*.
[b] Multiple regression coefficients result from each of these analyses. Each letter represents a different set of coefficients.

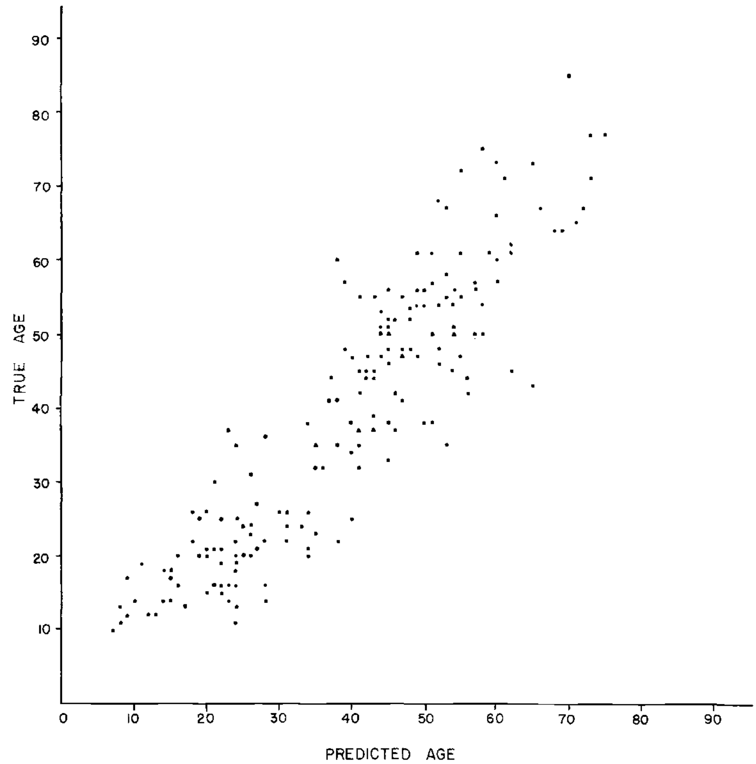

FIG. 5—*Regression of real age and predicted age as determined by multiple regression analysis, coefficient set D.*

population. There are four discrete levels on which the method can be modified and refined: the sample, the technique, the evaluation, and the analysis.

In this work, contributions were made at two levels: technique and analysis. A technique was developed for serial sectioning of undecalcified teeth, making possible accurate evaluation of multi-rooted and otherwise asymmetrical teeth (Fig. 6).

Multiple regression analysis was used to weight the contribution of each variable to the accurate determination of age. Also, the class variables of position, race, sex, and presence or absence of periodontal disease were added to the several quantitative variables already in use by other investigators (Appendix A).

We will continue to modify the formulas so they may be used when certain variables such as race, sex, attrition, or paradentosis are not known. We are also conducting chemical analyses of tooth enamel and working out age curves for such changes as calcium content.

In conclusion, the class variables—tooth position, race, sex, and presence or absence of periodontal disease—are all significant variables for age determination analysis.

Also, serial sectioning of undecalcified teeth is useful in that it makes possible the utilization of multi-rooted and asymmetrical teeth in age determination studies.

Most important of all, the Gustafson method is found to be sound in the basic principle of using multiple variables. Multiple regression analysis of separate point values, however, provides a better regression for a single set of data than does a single regression analysis of point totals. At this time, it is not proven that multiple regression analysis can provide a better model for the entire population. An increase in sample size and

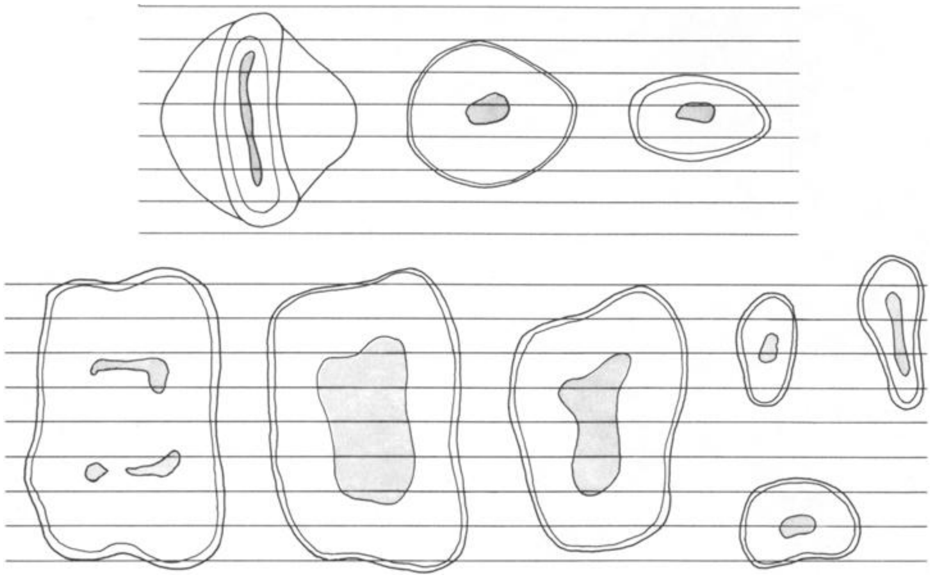

FIG. 6—*Cross sections of an incisor and a molar demonstrate the usefulness of serial sectioning. Whereas a single central section may provide all necessary information from single-rooted teeth, serial sections are requisite for multi-rooted teeth. The apical foramina are often contained in different sections, apart from the central section.*

further quantification of variable evaluation should improve the predictive quality of the multiple regression method.

Acknowledgment

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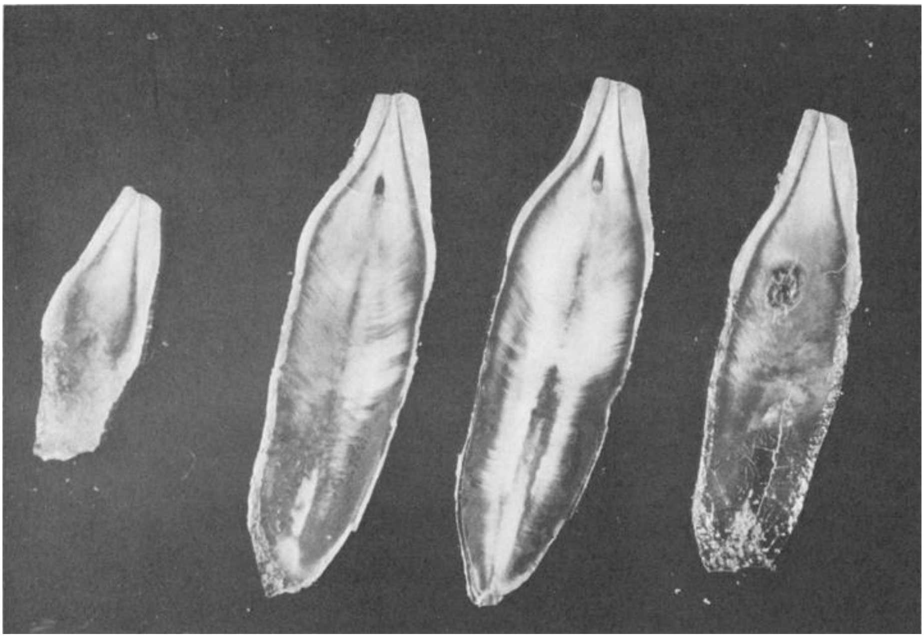
APPENDIX A

The following is a key which is applicable to all four coefficient set formulas. With regard to the use of class variables (tooth position, race, sex, and periodontal disease), if a specific qualification is not met, 0.00 is entered. For example: in the set A formula, −7.35 is entered if the tooth donor is a male; 0.00 is entered if the donor is a female. The continuous variables present no such complication. The coefficient is simply multiplied by the value of the variable. Examples demonstrating the use of coefficient set D are found in Figs. 7, 8, and 9.

Key to Formulas

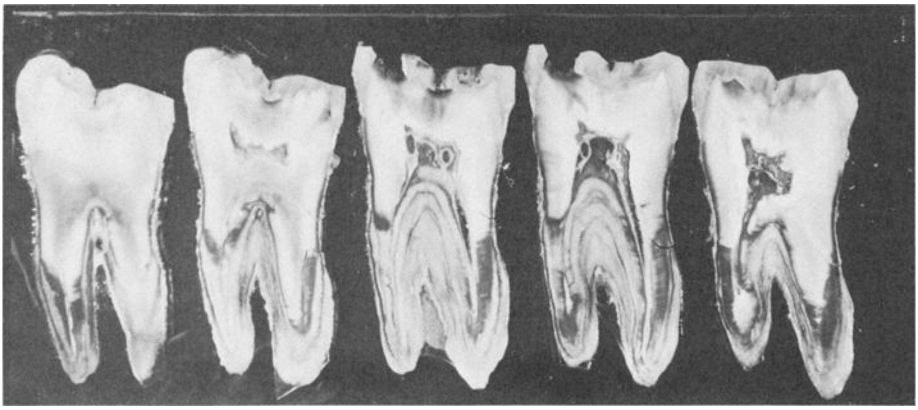
Position 1, central incisor
Position 2, lateral incisor
Position 3, canine



Position 2		True age 76 years, 10 months
Race	W	Predicted age (y) = 18.66
Sex	M	
Pd	no	− 0.63
A	1.5	+ 2.29
P	3.0	+ 3.89 (1.5)
S	3.0	+ 16.18 (3.0)
C	1.0	− 2.25 (3.0)
R	3.0	+ 2.66 (1.5 × 3.0)
T	3.0	− 9.45 (1.5 × 3.0)
		+ 8.37 (1.5 × 3.0)
		= 75.055

FIG. 7—*An example of the use of multiple regression coefficients, set D. Tooth is from the working sample and is serially sectioned according to the procedure described.*

Position 4, first premolar
Position 5, second premolar
Position 6, first molar
Position 7, second molar
Position 8, third molar
W, white
B, black
F, female
M, male
Pd, presence of periodontal disease
A, attrition
P, paradentosis (gingival recession)
S, secondary dentin
C, cementum apposition
R, root resorption
T, transparency



Position 7	True age 57 years, 8 months
Race B	Predicted age (y) = 18.66
Sex F	
Pd yes	− 4.89
A 1.0	+ 1.71
P 1.5	+ 3.89 (1.0)
S 2.0	+ 16.18 (2.0)
C 2.5	+ 2.66 (1.0 × 1.5)
R 0.0	− 9.45 (1.0 × 2.0)
T 2.0	+ 8.37 (1.0 × 2.0)
	+ 9.67 (1.0)
	− 5.21 (2.0)
	= 52.81

FIG. 8—*An example of the use of multiple regression coefficients, set D. Tooth is from the working sample and is serially sectioned according to the procedure described.*

Position 6	True age 10 years, 1 month
Race B	Predicted age (y) = 18.66
Sex M	
Pd no	− 13.88
A 0.5	+ 3.89 (0.5)
P 0.0	= 6.725
S 0.0	
C 1.5	
R 0.0	
T 0.0	

FIG. 9—*An example of the use of multiple regression coefficients, set D. Tooth is from the working sample and is serially sectioned according to the procedure described.*

Coefficient Set A Formula

y = 71.79 + position + race + sex + 7.11A − 66.36P + 21.72S − 2.08C + 6.34AP − 6.48AS − 12.43AC + 8.60AR + 19.78AT − 43.52PS + 23.87PC + 4.04PR + 37.01PT + 52.51SC + 7.45SR − 6.09ST − 33.00CR − 48.30CT + 3.95RT (following items if Pd present) − 22.85 − 23.85A + 67.13P + 37.38S − 18.58C + 2.87R − 78.63T

Values

Position: 1 = −5.56; 2 = +5.00; and 3 = 0.00.
Race: W = 0.00 and B = −2.36.
Sex: F = 0.00 and M = −7.35.

Coefficient Set B Formula

y = 13.70 + position + race + sex + 5.40A − 1.42P + 5.98S + 6.62C + 6.86AP − 5.62AS − 4.92AC + 1.59AR + 3.12AT + 1.62PS − 1.42PC + 0.97PR + 0.07PT + 0.59SC + 1.57SR + 2.18ST − 4.05CR + 0.28CT − 3.13RT (following items if Pd present) − 18.60 + 26.38A − 0.04P + 3.87S + 2.51C + 1.89R − 7.70T

Values

Position: 6 = −8.11; 7 = −0.90; and 8 = 0.00.
Race: W = 0.00 and B = +2.13.
Sex: F = 0.00 and M = +1.12.

Coefficient Set C Formula

y = 14.79 + position + race + sex + 3.84A + 1.08P + 9.40S + 3.66C + 2.24R + 3.68T + 1.04A^2 − 1.63P^2 + 0.15S^2 + 0.18C^2 − 0.72R^2 + 0.52T^2 + 3.42AP − 9.38AS − 0.56AC − 0.41AR + 7.33AT + 1.20PS − 0.48PC + 0.94PR + 2.00PT + 2.11SC − 1.82SR − 0.18ST − 0.89CR − 3.67CT − 0.65RT (following items if Pd present) − 5.07 + 11.27A + 2.02P + 4.18S + 1.74C − 2.76R − 8.60T

Values

Position: 1 = −17.18; 2 = −1.40; 3 = −10.92; 4 = −7.37; 5 = −4.23; 6 = −15.66; 7 = −7.93; and 8 = 0.00.
Race: W = +4.12 and B = 0.00
Sex: F = +2.89 and M = 0.00.

Coefficient Set D Formula

y = 18.66 + position + race + sex + 3.89A + 16.18S − 2.25R + 2.66AP − 9.45AS + 8.37AT (following items if Pd present) + 9.67A − 5.21T

Values

Position: 1 = −12.96; 2 = −0.63; 3 = −5.28; 4 = −5.85; 5 = −3.11; 6 = −13.86; 7 = −4.89; and 8 = 0.00.
Race: W = +2.29 and B = 0.00.
Sex: F = +1.71 and M = 0.00.

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