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W. R. Maples, [1] *Ph.D.*

An Improved Technique Using Dental Histology for Estimation of Adult Age

Teeth are the most durable structures in the human body. In many archeological sites or forensic cases, the teeth are the only human remains. This is particularly true when soil is extremely acidic. In other cases, such as transportation disasters, the remains may be so damaged that dental aging is necessary.

Like other techniques such as the appearance and fusion of ossification centers, many of the traditional techniques of dental aging are most useful during maturation. Other dental techniques, such as that of Gustafson [*1,2*], are useful throughout adult life and have the potential of offering considerable accuracy, perhaps being the techniques of choice even when more complete skeletal remains are present.

The Gustafson technique of dental aging does not seem to be widely used in this country. Publication of the wrong regression by Gustafson, testing the regression against the sample used to derive the formula, and various other statistical errors may have contributed to this apparent reluctance to use the technique [*3*]. While attempts to improve the technique have never been particularly successful [*4*], the general concept pioneered by Gustafson and others [*5-7*] remains promising. Several lines of improvement remain possible, particularly the consideration of tooth position in the calculations. It does not seem possible that one regression line can give the same precision for all the teeth given the morphological variation of the teeth as well as the extreme differences in eruption times for the various teeth.

The present investigation is still another attempt to improve the precision of the technique by using the scoring system of Gustafson [*2*] while simultaneously reducing the number of age-related changes to be considered.

Sample and Methods

The sample was the same one used by Burns and Maples [*4*]. A total of 355 teeth were obtained from a Florida dental clinic. These were randomly divided into a working sample (approximately 80%) and a control sample (approximately 20%). Longitudinal sections of approximately 250 to 350 μm were cut with a diamond-blade thin-section saw. The scores derived in the Burns and Maples investigation were also used in this study. Only the statistical treatment of these scores was different.

The multiple regression subprogram of the Statistical Package for the Social Sciences (SPSS) [*8*] was used throughout the study, even when only one variable was to be regressed

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[1] Curator and chairman, Department of Social Sciences, Florida State Museum and professor, Department of Anthropology, University of Florida, Gainesville.

against a second. All regression line data and standard error of the estimates for those lines were derived by this subprogram.

Besides tooth position, only the six changes described by Gustafson [1] were used: attrition, paradentosis (gingival recession), secondary dentin, cementum, root resorption, and root transparency. In the Gustafson technique, scores of 0 to 3 (by half points) are given to each of these six changes and the total is compared to the regression line. A complete discussion of these can be found in the Gustafson publications [1,2] and in Burns and Maples [4].

The first stage of analysis was to regress the total scores for the six changes against age for each of eight tooth positions: central incisors, lateral incisors, canines, first premolars, second premolars, first molars, second molars, and third molars (Positions 1 through 8, respectively). Since the SPSS subprogram also indicated the regression coefficient for each of the six changes, a measure of the effect of each individual change on the overall regression coefficient could be considered. This allowed the investigator to reduce the number of changes used in the regression by eliminating those poorly correlated with age.

Then the total scores of all changes except root resorption were regressed against age for each tooth position. Next, total scores for secondary dentin, cementum, and root transparency were used.

Multiple regression was then carried out by regressing each of the six changes independently against age, instead of adding the scores together before regressing them. Then the number of changes was again reduced from the original six to use only those changes having the greatest correlation with age so the precision of the formulas could be improved. In this way, a new technique could be developed that would give both the desired increased precision as well as the increased simplicity. Those formulas that displayed promise of improved precision were tested against the control sample.

Results

Root resorption was by far the worst of the six changes. The correlation coefficient was consistently low, even negatively correlated for most tooth positions. Root transparency was the best, followed by secondary dentin, attrition, paradentosis, and cementum.

The standard errors of the estimates of the regression formulas for each position using all six changes added together offered little improvement over the Gustafson technique as modified by Maples and Rice [3]. Elimination of root resorption improved the results for all tooth positions except Position 3 (canine). In most cases, the standard error of the estimate was reduced 20 to 30%.

The set of linear regressions produced by using the total scores for secondary dentin, cementum, and root transparency regressed against age were considered because paradentosis is often impossible to determine long after decomposition of soft tissue and because of population differences in attrition resulting from diet. The resulting set of formulas was better than those using five changes for only one tooth position (Position 1). In four cases (Positions 2, 3, 4, and 5), the results were worse than when all six changes were used.

Multiple regressions were then developed for various combinations of the six age changes. Eight combinations of tooth changes were used (Table 1). Of these, APSCT showed the greatest promise, but there was not a great deal less precision in any of the combinations. The two extremes, APSCRT and ST, were never the best nor the worst for the eight tooth positions even though one considered all six changes and the other considered only two of them.

Complete analysis was carried out on combinations APSCRT, APSCT, AST, SCT, and ST, selectively eliminating changes for the various reasons previously discussed. These

TABLE 1—*Combinations of changes regressed against age by multiple regression.*

Combinations			Key	
APSCRT	ASCT	AST	A = attrition	C = cementum
APSCT	PSCT	PST	P = paradentosis	R = root resorption
APST	SCT	ST	S = secondary dentin	T = root transparency

analyses included testing the regressions against the control sample to obtain the standard error of the estimate ($s_{y \cdot x}$). Overall formulas ignoring position and formulas with weights (regression slopes) for position were also developed and tested. The resulting data are reported in Tables 2 and 3. The standard error resulting from use of the Gustafson formula on the control sample is also shown.

The multiple regression formulas show considerable reduction in the standard error over previous techniques when tested on the control sample. There is more than 50% reduction in the standard error for some positions, such as Position 7, when the individual tooth position standard errors are compared with the standard error derived with the Gustafson formula. In fact, all formulas for tooth Position 7 show consistently good results.

The overall formulas that are weighted for tooth position show approximately 20% improvement over the Gustafson technique (which ignores tooth position). The overall formulas for all positions without any weighting for tooth position show little or no improvement over the Gustafson formula.

The simplest overall formula with tooth position weighted (ST) is the best, along with SCT. Both ST and SCT have a standard error of the estimate of ±9.1 when tested on the control sample.

The complete regression formulas for APSCT, which show the best standard error for any tooth position (Position 7), and ST, which is the simplest set of formulas as well as the best overall formula with position weighting, are given in Table 4. The score as defined by Gustafson for the changes (such as secondary dentin or transparency) is substituted for the corresponding letter abbreviation in the formulas, thus being multiplied by the slope immediately preceding the letter.

The average age of the teeth in the control sample was 38.8 years. The average age of the sample estimated by the ST overall position weighted formula was 37.5 years. The average age estimated by the individual position ST formulas was 37.8 years, suggesting that these formulas do not consistently under- or over-age the unknown sample.

Discussion

Multiple regression gives increased precision along with a decreased number of variables. Tooth Position 7 (the second molar) gives excellent results. Indeed, the standard error of the estimate with the APSCT Position-7 formula (±5.00 years) is one of the smallest published for any technique to estimate the age of a person throughout the full range of adult life. Even the overall formulas for all positions (weighted) are much better than most techniques and compare closely with the standard errors for osteon aging of bone.

The ST overall position weighted formula probably gives the best results for all teeth and only requires the scoring of secondary dentin and root transparency. This means that teeth with broken crowns, no evidence of periodontal attachment, and lost cementum may still yield accurate age estimates. It also means that this technique can be used on other populations, contemporary and prehistoric, with less fear that differences in dietary practices will lessen the precision. The data resulting from the Burns and Maples investigation [*4*] displayed little differences in dental aging between blacks and whites and be-

TABLE 2—*Comparison of regression data for APSCRT and APSCT multiple regression techniques and the Gustafson technique.*[a]

	APSCRT					APSCT						
	Working Sample			Control Sample		Working Sample			Control Sample		Gustafson Technique	
Position	Multiple Regression	$s_{y \cdot x}$	n	$s_{y \cdot x}$	n	Multiple Regression	$s_{y \cdot x}$	n	$s_{y \cdot x}$	n	$s_{y \cdot x}$	n
1	0.95	8.0	14	10.1	6	0.95	7.5	14	10.1	6	...	...
2	0.95	10.1	12	10.1	3	0.93	9.6	12	10.1	3	...	...
3	0.94	13.4	8	10.1	4	0.94	10.1	8	10.1	4	...	...
4	0.95	7.3	16	10.1	2	0.95	7.1	16	10.1	2	...	...
5	0.90	10.6	15	10.1	3	0.90	10.1	15	10.1	3	...	...
6	0.86	8.5	49	12.1	14	0.85	8.7	49	11.0	14	...	...
7	0.93	7.1	41	6.0	10	0.92	7.1	41	5.0	10	...	...
8	0.96	6.7	15	14.7	9	0.94	7.5	17	13.7	9	...	...
Position not considered	0.85	10.2	169	11.1	51	0.84	10.4	169	10.6	51	11.3	51
Weighted for position	0.90	8.5	169	10.2	51	0.90	8.6	169	9.3	51	...	...

[a] $s_{y \cdot x}$ was not determined for cases where n was less than six.

TABLE 3—*Comparison of regression data for AST, SCT, and ST multiple regression techniques.*

	AST					SCT					ST				
	Working Sample			Control Sample		Working Sample			Control Sample		Working Sample			Control Sample	
Position	Multiple Regression	$s_{y \cdot x}$	*n*	$s_{y \cdot x}$	*n*	Multiple Regression	$s_{y \cdot x}$	*n*	$s_{y \cdot x}$	*n*	Multiple Regression	$s_{y \cdot x}$	*n*	$s_{y \cdot x}$	*n*
1	0.91	7.6	20	9.0	8	0.90	7.7	20	9.2	8	0.89	7.6	21	9.1	8
2	0.89	9.8	13	9.0	4	0.89	10.0	13	9.2	4	0.88	9.6	13	9.1	4
3	0.86	10.2	8	9.0	5	0.79	11.0	11	9.2	5	0.76	11.0	12	9.1	5
4	0.92	7.4	18	9.0	2	0.76	13.0	18	9.2	2	0.77	12.2	19	9.1	2
5	0.89	8.7	17	9.0	5	0.83	10.8	17	7.1	7	0.83	10.5	17	7.6	7
6	0.85	8.7	53	11.4	16	0.85	8.1	62	11.2	19	0.85	8.1	62	11.1	19
7	0.90	7.7	48	5.1	12	0.89	8.0	55	6.8	12	0.88	8.1	58	6.8	12
8	0.87	8.6	22	13.2	9	0.83	9.3	30	12.9	9	0.83	9.1	34	12.0	9
Position not considered	0.81	10.6	199	11.4	61	0.80	10.7	226	10.9	66	0.80	10.6	236	10.9	66
Weighted for position	0.88	8.9	199	9.7	61	0.87	9.1	226	9.1	66	0.86	9.1	236	9.1	66

TABLE 4—*Regression formulas that may be used to estimate age.*

Position Formulas for ST

Age = 3.89S + 14.23T + 15.28	± 9.1 SE[a]	(Position 1)
= 6.51S + 12.55T + 25.16	± 9.6 SE	(Position 2)
= 18.67S + 11.72T + 21.94	± 11.0 SE	(Position 3)
= 2.82S + 15.25T + 19.65	± 12.2 SE	(Position 4)
= 4.79S + 15.53T + 17.99	± 7.6 SE[a]	(Position 5)
= 11.28S + 5.32T + 10.86	± 11.1 SE[a]	(Position 6)
= 6.99S + 10.86T + 19.31	± 6.8 SE[a]	(Position 7)
= 4.71S + 12.30T + 24.57	± 12.0 SE[a]	(Position 8)

Position Formulas for APSCT

Age = 4.23A − 4.18P + 2.98S + 8.63C + 18.15T − 3.35	± 10.1 SE[a]	(Position 1)
= 3.47A + 6.78P + 13.67S + 4.21C − 0.99T + 12.73	± 9.6 SE	(Position 2)
= 11.02A + 7.35P + 18.52S + 0.35C + 7.54T − 1.14	± 10.1 SE	(Position 3)
= 20.16A − 0.85P − 3.01S + 2.65C + 13.23T + 5.96	± 7.1 SE	(Position 4)
= 15.88A + 3.23P + 2.46S − 0.53C + 14.73T + 1.79	± 10.1 SE	(Position 5)
= 2.09A + 3.33P + 9.08S + 1.47C + 4.38T + 6.32	± 11.0 SE[a]	(Position 6)
= 8.91A + 2.23P + 7.64S + 0.45C + 6.99T + 12.10	± 5.0 SE[a]	(Position 7)
= 5.55A − 0.92P + 4.30S − 0.80C + 13.77T + 24.76	± 13.7 SE[a]	(Position 8)

Formulas Weighted for All Positions

Age = 6.54S + 10.88T + 16.08 + position value ± 9.1 SE[a]

Position values

Position 1 = 0.00	Position 5 = 5.21
Position 2 = 11.24	Position 6 = −5.37
Position 3 = 13.18	Position 7 = 3.73
Position 4 = 4.39	Position 8 = 8.04

Age = 7.09A + 2.56P + 5.20S + 0.26C + 9.14T + 2.32 + position value ± 9.3 SE[a]

Position values

Position 1 = 0.00	Position 5 = 11.69
Position 2 = 15.59	Position 6 = 1.98
Position 3 = 16.07	Position 7 = 11.65
Position 4 = 10.14	Position 8 = 18.44

[a] Standard error of the estimates used in these formulas are those derived from tests on the control sample.

tween males and females, which further suggests that the ST overall formula may be used with other populations with a relative measure of confidence. Since secondary dentin and transparency are two of the easiest to evaluate of all of the changes, observer error may be lessened.

The sample size, especially for some tooth positions, was not optimal in this investigation (although considerably better than the 41 total teeth in the Gustafson sample). The control sample was correspondingly small. The use of a control sample to test any statistical technique is absolutely necessary. Only such tests give the true measure of the precision of techniques. Indeed, it is possible to derive complex multiple regression formulas by means of computers that are amazingly precise on the working samples, but not particularly good when tested on other samples. An example of such a technique is Set A in Table 1 of Burns and Maples [*4*]. In this case, it was tested against the control sample and found to be only slightly better than the Gustafson technique as tested against the same sample.

Further improvement can be made with the technique presented by an increase of sample size and the substitution of quantifiable data instead of the Gustafson scores. The use of objective measurements instead of subjective scores would make the technique more standardized in the hands of other observers. It is possible that some improvement might also result from treating maxillary and mandibular dentition separately. The author has already begun collecting much larger working and control samples that will be scored with actual measurements of the thickness of secondary dentin, cementum, and the relative area of root transparency. With those refinements, it is believed that histological age estimates of adult human dentition will be as accurate as biological variation will allow.

Conclusions and Summary

Multiple regression analysis has allowed considerable improvement of age estimates on adult human teeth. Not only were the estimates more precise, but they also involved fewer variables, decreasing the probability of observer error. There was consistent evidence that the second molar (Position 7) was the best to use for histological aging techniques. The reduction in variables to just secondary dentin and root transparency has also resulted in a technique that can be used with some confidence in populations other than the one sampled. Thus, dental aging can be used in the same way as epiphyseal fusion, osteon aging, cranial sutures, and changes in the pubic symphysis that have been used with other contemporary and prehistoric populations.

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Address requests for reprints or additional information to
W. R. Maples, Ph.D.
Florida State Museum
University of Florida
Gainesville, Fla. 32611