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Further Comments on the Estimation of Error Associated with the Gustafson Dental Age Estimation Method

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ABSTRACT: Many researchers in the field of forensic odontology have questioned the error estimates stated in Gustafson's [*1*] paper outlining the relationship between certain dental attributes and age. In a substantial re-working of Gustafson's data, Maples and Rice [*2*] corrected Gustafson's regression statistics and found that the error associated with the age estimate was nearly double that claimed by Gustafson. We offer another statistical analysis of Gustafson's data and find that the errors calculated by Maples and Rice were also in error, being about a year too small. We give a formula for what we believe to be the correct treatment of errors in such cases, but conclude by observing that there is an urgent need for a more rigorous study of the traits first tabulated by Gustafson.

KEYWORDS: odontology, Gustafson method, dental aging, human identification, error

Since 1950, when Gustafson [*1*] published his seminal paper on adult dental age estimation, there has been a steady trickle of papers into the forensic literature all offering improvements to the basic Gustafson age estimation technique, but still based in some way upon Gustafson's age estimation criteria [*3–5*]. However, a common theme commented upon by many authors [*3,6,7*] is the apparent irreproducibility of Gustafson's original error estimate for the technique. This question has been examined in most detail by Maples and Rice [*2*] who identified a number of serious problems with the statistical treatment of the original data, but failed to substantiate Gustafson's [*1*] original error estimate of ±3.63 years. They [*2*] calculated an associated error of ±7.03 years using what can be reconstructed from Gustafson's original data. We offer some further statistical comment on both Gustafson's [*1*] original paper and Maples and Rice's [*2*] re-analysis of that work, in the hope of making what is undoubtedly still a useful and applicable technique more accessible to forensic odontologists and others (such as archaeologists) who might be interested in reconstructing past age distributions from dental evidence.

Summary of Gustafson's Original Procedure

Gustafson [*1*] first formulated observations of macrostructural changes in teeth into a workable system for adult age estimation. His method was based upon six age related changes, assigning points upon an ascending scale of 0 to 3 according to the severity of the change. These changes are:

i) A—attrition—the gradual wear of the enamel on the occlusal surface, used [*8*] as a method of aging adult populations;
ii) S—secondary dentine apposition–age related build-up of dentine on the walls of the pulpal chamber;
iii) P—periodontitis—the irregularity in the form of the cementum and root dentine caused by ongoing repositioning of the periodontal ligament;
iv) C—cementum build-up, related to periodontosis, where the continuous repositioning of the tooth in the alveolar bone necessitates extra layers of cementum [*9*];
v) R—root resorption—the gradual resorption of the root apex (a process little understood in terms of oral biology);
vi) T—root transparency—the tendency of root dentine in thin (300 μm) sections to appear to be transparent in transmitted light from the apex upwards (termed sclerotic dentine).

This latter change is caused by the formation of spicules of mineralized material occluding the tubule structure of the dentine, so that the tubules have the same refractive index as the intertubular dentine and become transparent [*10,11*]. Again, the formation of sclerotic dentine is a little understood phenomenon, but one that appears to be highly correlated with age and forms the basis for Bang and Ramm's [*3*] method of age estimation.

Gustafson [*1*] summed the points allocated to each of the six age-related changes listed above and then calculated a regression line from a sample of extracted teeth of known age. He claimed a 'standard error' (see the following) of about 4.5 years, but other workers have not managed to replicate this figure and further calculations based upon Gustafson's published data yield a slightly different regression line and show that a more realistic error estimation is ±7.03 years [*2*].

In a subsequent development of the Gustafson technique, Johanson [*4*] used essentially the same age indicators, but concluded that intermediate stages of severity could be detected reliably, resulting in a system of seven ordinal stages for each of the six variables, as opposed to Gustafson's original four. Instead of Gustafson's crude summation of total points for a given individual followed by linear regression of total point score against age, Johanson [*4*] used a multiple regression of each variable against age. It is worth noting that neither Johanson nor Gustafson differentiated between tooth locus in their regression analysis. In a further refinement, Bang and Ramm [*3*] concentrated on measurements of root dentine transparency as the sole age indicator. They used 926 teeth from 265 known age individuals and regressed the average linear root dentine transparency measured in millimetres

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against known age at extraction for each tooth locus in the dentition. Their estimated errors were between 7 and 13 years and depended upon which tooth was under consideration.

Maples' and Rice's Criticisms of Gustafson's Work

Maples and Rice [2] suggest that Gustafson's regression line, which was used to calculate ages for the whole sample of 41 teeth, was calculated from 19 teeth (shown as Fig. 4 in Gustafson's paper). Some of the same teeth were apparently subsequently used in a test of the accuracy of that regression line, which, as Maples and Rice correctly point out, is a very unsound practice and does not constitute a test of the model. In fact, this does not appear to be the case. Gustafson clearly stated (p. 51) that "the regression line was calculated by current formula from the data in Table 1." Gustafson's Table 1 contains data on only eight teeth (numbered 1 to 8), but does not give the total point count on each tooth, so it is impossible to recalculate the equation of the regression line (given by Gustafson as "Age = $11.43 + 4.56x$," where x is the total points count). Confusingly, Gustafson's Table 5, which contains the most complete data set of 41 teeth, lists samples 1 to 4, but not 5 to 8 (his Table 5 is reproduced here as Table 1). This leads us to conclude that the regression equation is based on only eight samples, not 19 as suggested by Maples and Rice from their viewing of Gustafson's Fig. 4, which appears to be simply illustrative, and that four of the eight were subsequently used in a validation of the model.

Despite this understandable confusion, the main thrust of Maples and Rice's criticism is aimed at Gustafson's derivation of his regression line, and the subsequent calculation of the dispersion of points about that regression line. They observe that Gustafson calculated the "average deviation" of the known ages from the ages predicted by his regression line (presumably by calculating the average value of the mean deviation, irrespective of sign), and subsequently used this as a measure of the accuracy of the method. They correctly state that average deviation, although being a valid measure of dispersion, is not the same as standard deviation and does not allow the same probabilistic interpretation, as Gustafson appears to assume. We have also attempted to derive the figure of "±3.63 years" from the average deviations of the data given in Gustafson's Table 5, without success. There is a discrepancy in notation used within Gustafson's paper, and between the two papers: Gustafson says (p. 51) that "the average deviation of a

TABLE 1—*Reproduction of Gustafson's Table 5.*

Tooth Number	Attrition (A)	Peridontosis (P)	Secondary Dentine (S)	Cementum Apposition (C)	Root Resorption (R)	Transparency (T)	Total Points	Real Age (years)	Estimated Age (years)
34	0	0	0	0	0	0	0	11	12
37	0	0	0	0	0	0	0	12	12
32	0	0	0	1	0	0	1	12	16
14	0	0	0	1	0	0	1	13	16
2	0	0	0	1	0	0	1	15	16
12	1	0	0	0	0	0	1	16	16
28	0	0	0	1	0	0	1	17	16
39	0	0	0	1	0	0	1	23	16
45	1	2	0	1	0	0	4	23	29
33	0	0	0	1	0	0	1	25	16
27	1	1	1	1	0	0	4	28	29
20	2	2	2	1	0	1	8	35	47
3	1	1	0	2	2	0	6	37	38
30	0	1	0	1	3	0	5	37	34
9	2	1	1	2	0	1	7	38	43
13	1	1	2	2	0	1	7	38	43
42	1	0	2	2	2	1	8	39	47
21	2	2	2	1	1	0	8	39	47
23	2	2	1	1	1	1	8	45	47
25	1	2	1	1	1	1	7	45	43
44	1	0	0	2	0	2	5	48	34
38	1	0	0	2	2	1	6	48	38
41	1	1	2	3	2	0	9	48	52
22	2	0	2	1	0	1	6	49	38
26	2	1	2	1	1	1	8	49	47
17	2	2	3	1	1	2	11	50	61
19	2	1	3	2	0	2	10	51	56
11	1	0	1	2	3	2	9	51	52
18	2	1	2	2	2	1	10	51	56
46	2	2	2	1	1	1	9	52	52
43	1	1	3	3	0	1	9	52	52
40	1	1	3	2	2	2	11	52	61
15	0	2	3	1	1	2	9	53	52
24	1	2	3	1	0	1	8	55	47
47	2	1	1	2	1	2	9	55	52
4	2	2	2	3	2	1	12	59	65
29	2	2	1	1	2	1	9	64	52
1	0	2	3	2	1	1	9	64	52
10	2	2	3	2	2	1	12	65	65
16a	3	1	2	3	0	1	10	69	56
16b	1	1	2	2	3	1	10	69	56

value from the regression line ($\delta_y - Y$), *i.e.* the error of the estimation, was: $\delta_{sy} - Y = \pm 3.63$ years." Maples and Rice (p. 169) refer to this equation as "$\sigma_{xy} - Y$," and give the equation that they say should have been used as "$s_{y.x} = (Y - Y')^2/(n - 2)$." We give what we believe to be a more appropriate treatment below. If one simply calculates the average value of the absolute difference between the known and predicted age for the 41 samples as tabulated by Gustafson in Table 5, one obtains a value of 5.34 years. Moreover, when the average deviation is calculated from the estimated ages and known ages for the eight samples in Gustafson's Table 1, it is found to be 8.63 years (acknowledged as 9 years in the text), not 3.63 years as finally stated by Gustafson. We must therefore concur with Maples and Rice that this figure is incorrect as an estimate of the error associated with the regression, and that Gustafson's probabilistic interpretation of the figure is also incorrect.

Maples and Rice then recalculated a regression line, and the errors about that regression line, based upon the entire dataset published in Table 5 of Gustafson's paper. By regressing age as the dependent variable (y) and the point count as the independent variable (x) (which we suggest is the wrong way round), they obtain an equation of the form:

$$y = 4.26x + 13.45 \qquad r = 0.912$$

with which we entirely concur. Using their formula for the standard error of the estimate (as shown), they give a value for the error as ±7.03 years, although they note that this error term will not be uniform across the entire range of predicted ages. We attempt as follows to give a more accurate value for this term.

One final point of difference between the two papers is that of the repeatability of the estimate of the point count for a particular tooth (essentially the precision of the measurement). Gustafson examines the measurement of point values on two separate occasions—his method of "double determinations"—and concludes that there is no significant difference between the two occasions upon which the teeth were examined (a mean difference of 0.27 points ±0.17). Maples and Rice recalculated the differences between Gustafson's point values on the two occasions and find that the difference is considerably larger than this (mean error 0.76 points), but they do not elaborate further upon the significance of this.

Our conclusion at this stage is that the original pioneering work of Gustafson is riddled with statistical inconsistencies, and that his original conclusions with regard to the accuracy of his method cannot be upheld. This observation has been made several times before, and it is probably not worth delving further into data which is now 44 years old, using a method that has largely been superseded by the more refined approaches of Johanson [*4*] and Bang and Ramm [*3*]. Our substantive point is that the reconsideration carried out by Maples and Rice is also capable of further improvement, and we go on to develop this point below. It is worth noting, however, that Gustafson continuously re-evaluated his age estimates, even from table to table within the original publication, and was critically aware of the potential errors resulting from differences in dental hygiene between individuals, and the effects of differential tooth development time from tooth to tooth within the dentition.

Further Comment on Maples' and Rice's Work

After their failure to replicate from Gustafson's published data both the relationship between points and age and the errors on this estimate, Maples and Rice recalculated a better estimate of these from the data published in Gustafson's Table 5, as discussed. In order to relate age and points count they calculated a line of regression of y on x where y was the known age and x the Gustafson points value. We suggest that this is the wrong way round, since the regression calculation assumes that all errors are in the y direction, that is in the known age, which is not the case. In doing this type of regression, we have to assume that any error in the x variable is small compared to that in the y variable, which strongly suggests that age should be chosen as the x axis, and points count as y. (It also suggests that errors associated with rounding the age to whole years should be avoided if possible.) This is an important point, because in general the line of regression of y on x is different from that of x on y, since the fit is obtained by minimizing residuals in one direction only. Furthermore, the error term associated with using such a calibration line to predict age values is not a constant, as is the case with the values quoted by both Gustafson and Maples and Rice. As noted by the latter authors, any errors on a regression line should form two parabolic curves about that regression line, that is, the error term should grow larger as the predicted value gets further from the centroid of the regression line. This is because the errors about a regression line have to take into account uncertainty in the slope of the line, but the calculations for this are somewhat tedious. However, there are now good approximations for this relationship, and with the aid of a computer spreadsheet it is now possible (as demonstrated below) to perform the full calculations relatively simply.

The problem posed is one of calculating the error about a calibration line derived from experimental data, and is the same as that faced by, for example, analytical chemists when trying to put error estimates on concentrations derived from a calibration curve. The basic method is outlined in Miller and Miller [*12*] (pp. 90–96) and consists of two parts: first is the calculation of the standard deviation of the regression of y on x ($s_{y/x}$) where y is the value of the measured quantity (that is, the point count for a given tooth), and x is independent variable—the known age for that tooth. Obviously, if the regression is carried out this way round, the equation needs rearranging before an estimate of age can be obtained from the points count. The equation for calculation of the standard deviation of the regression is:

$$s_{y/x} = \left\{\frac{\Sigma(y_i - \hat{y})^2}{n - 2}\right\}^{1/2} \qquad \text{(Eq 1)}$$

where

y_i = the total points for the i^{th} tooth
y = the points derived for the i^{th} tooth from the regression line
n = number of pairs of observations used in the regression

This is presumably the same equation as that quoted by Maples and Rice for this calculation, except we are doing it the other way round. Once this has been found, the predicted age for an unknown tooth can be calculated by inverting the regression equation, and the following approximated expression can be used to calculate the error associated with this age prediction (s_{xo}):

$$s_{xo} = \frac{s_{y/x}}{b}\left\{1 + \frac{1}{n} + \frac{(y_o - \bar{y})^2}{b^2\Sigma(x_i - \bar{x})^2}\right\}^{1/2} \qquad \text{(Eq 2)}$$

where

b = slope of the regression line
$s_{y/x}$ = standard deviation y on x derived from Equation 1

n = number of pairs of observations used in the regression
y_o = point count for the unknown tooth whose age is being predicted
y = mean of point counts for all observations used in the regression
x_i = age for the i^{th} tooth used in the regression
x = mean age for the whole sample used in the regression

Miller and Miller (p. 94) give a similar equation for the calculation of s_{xo} from m multiple observations of the value of y_o by substituting $1/m$ for 1 as the first term in the brackets, and using the average value for y_o. The results of this type of calculation are normally expressed as confidence intervals (normally 95%) for the predicted value, using the usual equation $x_o \pm ts_{xo}$, where the value of t is calculated from Student's t tables with $n - 2$ degrees of freedom, and n is the number of pairs of values used in the regression (*12*, p. 94).

These equations can now be used to derive an expression for the linear regression of age against dental points count and for the error term when this equation is used in a calibration mode using the data on 41 teeth which appear in Table 5 of Gustafson's original paper (reproduced in Table 1). The derived regression equation is:

$$\text{Points count at given age} = (0.1954 \times \text{age}) - 1.5268 \quad \text{(Eq 3)}$$

In order to use this to calculate the predicted age (x_o) from the points count of a tooth of unknown age (y_o), this equation must be inverted:

$$\text{Age for a given points count} = 5.117 \times (\text{points} + 1.5268) \quad \text{(Eq 4)}$$

The standard deviation of the regression ($s_{y/x}$) can now be calculated for this regression equation, using equation 1, which gives a value of 1.5048. Now we have this, we can generate an equation for the calculation of the error (s_{xo}) associated with the prediction of age (x_o) from an observation of points count (y_o), by substituting values into equation 2:

$$s_{xo} = 7.70 \left\{ 1.024 + \frac{(y_o - 6.854)^2}{439.55} \right\}^{1/2} \quad \text{(Eq 5)}$$

Once s_{xo} has been calculated for a particular prediction, it is a simple matter to convert the predicted age and associated error term into a 95% confidence interval of the prediction. In the case cited here (with 41 observations in the regression), the 95% value of t for 39 degrees of freedom is approximately 2.02, and so the 95% confidence interval of the estimate becomes:

$$\text{95\% CI of age estimate} = x_o \pm 2.02 s_{xo} \quad \text{(Eq 6)}$$

Discussion

These equations (4, 5, and 6) provide what we believe to be the best interpretation of the original data published by Gustafson (but not necessarily the best method for predicting age from dental points count). In order to see what effect this re-interpretation has on the predicted errors, we require an independent set of observations of Gustafson's points count (otherwise we would be committing the same error as Gustafson!). Very few forensic publications give this basic data, and so we have used these equations on a set of data gathered by one of the authors (DL) using 53 teeth from the Oral Surgery Department, St. Luke's Hospital, Bradford. The details of the observed points count, the predicted age using equation 4, the predicted associated error (equation 5) and the 95% confidence interval of the estimate (equation 6) are given in Table 2, together with the known age of the donor. It should be noted that these observations were made using Johanson's [*4*] refinement to Gustafson's method, in which the scores for each attribute are made on a half point scale. Rather than round these data to whole numbers, we have left them as they were recorded, since we do not believe that this factor alters the argument we are making.

Table 2 shows immediately that the use of equation 5 to calculate the associated error of the prediction only makes a small difference, unless the age is at one or other of the extremes. The average value for the predicted error (s_{xo}) in these data is 7.82 years, slightly greater than the value of 7.03 calculated by Maples and Rice, and considerably larger than Gustafson's original estimate of 3.63 years. More significantly, if one uses the 95% Confidence Interval for the estimate, one finds that the error in the estimate becomes approximately ±15.9 years. It is not therefore surprising to note that the true age in all cases falls within the 95% confidence interval of the estimate.

This re-analysis prompts us to question the validity of the error estimates cited by other authors such as Johanson [*4*], who performed a multiple regression of age against a refined scale of the six parameters used by Gustafson, and Bang and Ramm [*3*], who used root dentine transparency as their sole age estimation criteria. Johanson [*4*] cited a single error estimate of ±5.16 years (presumably at the one standard deviation level, that is, approximately 65% confidence interval). Bang and Ramm [*3*] quote different error estimates for each tooth locus, ranging from 7 to 13 years (again, presumably referring to the 65% level). Neither publication gives very much detail about the calculation of their errors, nor do they publish their full dataset (understandably, since both papers are based on work with about 1000 teeth). It is therefore impossible to know exactly how their errors were estimated, and how they compare with our re-evaluation of Gustafson's work.

The question that has to be asked is whether there is any point pursuing this type of analysis for estimation of age at death, given that a realistic prediction of the 95% confidence limit is ±15.9 years, rather than the figure originally given of 3.63 years. We believe the answer to be a qualified yes, but there are a number of prerequisites before further work can be carried out. From a theoretical viewpoint that linear regression of age against total points count, where each attribute is scored as a multistate variable, we estimate that the best time resolution achievable is around ±4 years.[2] Multiple regression gives more information about the value (in terms of age prediction) of each observation, but makes the calculation of associated error much more difficult. We are currently investigating the use of non-parametric statistics, more suited to the treatment of multistate observations [*13*]. We have also published elsewhere [*14*] a treatment which combines both Johanson's and Bang and Ramm's methodology, which gives a marginal improvement to the error estimate (approximately ±8 years at the 95% confidence level). Nevertheless, there is still a desperate need for a better dataset with which to develop these techniques further. Ideally, we require a large number of observations on specific teeth within the dentition from known age individuals (preferably whose age is known to better than whole years)

[2] Scaife, research student, personal communication 1994.

TABLE 2—*Calculated ages and errors for teeth from St. Lukes Hospital, Bradford, U.K.*

Individual Attributes					Gustafson's and Johanson's Attributes							Ages and Associated Errors			
Indiv.	Sex	Known Age	Tooth	Root	Attrition	Periodontosis	Secondary Dentine	Cementum Apposition	Root Resorbtion	Transparency	Total Points	Calculated Age	Standard Error	Lower 95% Confidence Limit	Upper 95% Confidence Limit
A001	M	35	L7	mesal	0.5	2	1	2	0.5	1	7	43.6	7.8	27.9	59.4
		35		distal	0.5	2	1	2	0	1	6.5	41.1	7.8	25.3	56.8
		35	L6	distal	0	2	2	1	0.5	0.5	6	38.5	7.8	22.8	54.3
A002	F	31	8L	distal	0.5	0	1	1	0.5	1	4	28.3	7.9	12.4	44.2
A003	F	32	6L	mesal	0.5	1	0.5	2	0	0.5	4.5	30.8	7.8	15.0	46.7
		32		distal	0.5	2	0.5	2	0	0.5	5.5	36.0	7.8	20.2	51.7
A004	M	30	L8	mesal	0	0	1	2	0	1	4	28.3	7.9	12.4	44.2
		30		distal	0.5	0	1	2	0	1	4.5	30.8	7.8	15.0	46.7
A005	F	18	L6	distal	0	0	1	0	0	0	1	12.9	8.1	−3.4	29.3
A006	F	36	7L	distal	0.5	1	1	1	1	1	5.5	36.0	7.8	20.2	51.7
		36	8L	mesal	0	2	1	1	0	1	5	33.4	7.8	17.6	49.2
		36		distal	0.5	1	2	2	0	1	6.5	41.1	7.8	25.3	56.8
A007	M	18	U7	mesal	0	0	1	0	0	0	1	12.9	8.1	−3.4	29.3
		18		distal	0	1	0.5	0	0.5	0	2	18.0	8.0	1.9	34.2
		18	U6	distal	0	0	0.5	0	0	0	0.5	10.4	8.1	−6.1	26.8
A008	M	34	8L	mesal	0.5	1	1	2	1	1	6.5	41.1	7.8	25.3	56.8
		34		distal	0.5	2	1	2	0	1	6.5	41.1	7.8	25.3	56.8
A009	F	30	8L	mesal	0	1	1	1	0	1	4	28.3	7.9	12.4	44.2
		30		distal	0	1	2	1	0	0	4	28.3	7.9	12.4	44.2
A010	F	19	U8	mesal	0	0	0	0.5	0	0	0.5	10.4	8.1	−6.1	26.8
		19		distal	0	1	0	0.5	0	0	1.5	15.5	8.0	−0.7	31.7
		19	8U	mesal	0.5	1	0	0	0	0	1.5	15.5	8.0	−0.7	31.7
		19		distal	0.5	1	0	0	0	0	1.5	15.5	8.0	−0.7	31.7
A011	M	23	8U	mesal	0	1	0.5	0	0.5	1	3	23.2	7.9	7.2	39.2
		23		distal	0	1	1	0	1	2	5	33.4	7.8	17.6	49.2
		23	L8	mesal	0	1	0	1	0	1	3	23.2	7.9	7.2	39.2
		23		distal	0	1	0	0	1	1	3	23.2	7.9	7.2	39.2
A012	M	27	U8	mesal	0.5	0	1	2	0	0.5	4	28.3	7.9	12.4	44.2
		27		distal	0.5	0	1	1	0	1	3.5	25.7	7.9	9.8	41.7
		27	L7	mesal	0	1	1	2	0	0.5	4.5	30.8	7.8	15.0	46.7
		27		distal	0	1	1	2	0	0	4	28.3	7.9	12.4	44.2
A013	M	30	U6	mesal	0	1	1	2	0	0.5	4.5	30.8	7.8	15.0	46.7
A014	M	37	8L	mesal	0.5	3	1	1	0	0	5.5	36.0	7.8	20.2	51.7
		37		distal	0.5	0	1	2	0	1	4.5	30.8	7.8	15.0	46.7
A015	M	35	8L	central	0.5	2	1	1	0	1	5.5	36.0	7.8	20.2	51.7
A016	F	35	L8	distal	0	1	2	1	2	0	6	38.5	7.8	22.8	54.3
A017	M	36	L6	mesal	0.5	1	1	2	1	0.5	6	38.5	7.8	22.8	54.3
		36		distal	0.5	1	0.5	2	1	1	6	38.5	7.8	22.8	54.3
A018	F	37	7L	mesal	0	2	1	1	1	1	6	38.5	7.8	22.8	54.3
		37		distal	0.5	1	1	1	1	2	6.5	41.1	7.8	25.3	56.8
		37	8L	central	0.5	1	1	1	1	1	5.5	36.0	7.8	20.2	51.7
A019	F	33	6U	mesal	0.5	2	0	1	0	1	4.5	30.8	7.8	15.0	46.7
		33		distal	0.5	0	2	2	0	0.5	5	33.4	7.8	17.6	49.2
A020	M	53	6U	mesal	1	2	1	1	0	2	7	43.6	7.8	27.9	59.4
		53		distal	1	2	1	1	0.5	2	7.5	46.2	7.8	30.4	61.9
		53	L8	mesal	1	2	1	1	0	2	7	43.6	7.8	27.9	59.4
		53		distal	0.5	1	1	1	0	1	4.5	30.8	7.8	15.0	46.7
A021	F	53	U7	mesal	0.5	1	3	1	1	2	8.5	51.3	7.8	35.5	67.1
		53		distal	0.5	1	2	2	1	2	8.5	51.3	7.8	35.5	67.1
		53	L1	central	1	2	2	2	0	2	9	53.9	7.8	38.0	69.7
A022	M	33	8U	mesal	0.5	1	1	1	1	1	5.5	36.0	7.8	20.2	51.7
		33		distal	0.5	1	1	1	1	1	5.5	36.0	7.8	20.2	51.7
A023	M	60	4U	central	0.5	2	2	1	1	2	8.5	51.3	7.8	35.5	67.1
		60	U1	central	1	2	1	1	0.5	2	7.5	46.2	7.8	30.4	61.9
		60	1U	central	1	2	2	1	0.5	2	8.5	51.3	7.8	35.5	67.1
B025	F	28	L8	mesal	0.5	1	0	1	0	0.5	3	23.2	7.9	7.2	39.2
		28		distal	0.5	1	0	1	0	0.5	3	23.2	7.9	7.2	39.2
		28	5U	central	0	0	1	1	1	0.5	3.5	25.7	7.9	9.8	41.7
B026	F	28	7U	mesal	0.5	1	1	1	0.5	0.5	4.5	30.8	7.8	15.0	46.7
		28		distal	0.5	1	1	1	0	0.5	4	28.3	7.9	12.4	44.2
		28	L8	mesal	0.5	0	1	1	0.5	1	4	28.3	7.9	12.4	44.2
		28		distal	0	0	1	1	0.5	0.5	3	23.2	7.9	7.2	39.2
B028	M	28	U8	central	0.5	1	1	0	0	0	2.5	20.6	8.0	4.5	36.7
		28	8U	central	0.5	1	1	0	0	0.5	3	23.2	7.9	7.2	39.2
B030	F	29	8U	mesal	0.5	0	0	1	0	0	1.5	15.5	8.0	−0.7	31.7
		29		distal	0.5	0	0	0	2	0.5	3	23.2	7.9	7.2	39.2
B032	M	28	U8	mesal	0.5	1	1	1	0	0.5	4	28.3	7.9	12.4	44.2
		28		distal	0.5	1	1	1	0	1	4.5	30.8	7.8	15.0	46.7
B033	F	29	U6	mesal	0.5	0	1	1	0	0	2.5	20.6	8.0	4.5	36.7
		29		distal	0.5	1	1	1	0	0.5	4	28.3	7.9	12.4	44.2
		29	7L	central	0.5	1	1	1	0	0.5	4	28.3	7.9	12.4	44.2
		29	8L	central	0.5	1	1	1	0	0.5	4	28.3	7.9	12.4	44.2
B034	F	29	8U	central	0.5	0	2	1	0	0.5	4	28.3	7.9	12.4	44.2
B035	F	29	7L	mesal	0.5	0	1	0	2	0	3.5	25.7	7.9	9.8	41.7
		29		distal	0.5	1	0	1	2	0	4.5	30.8	7.8	15.0	46.7
B036	F	29	6U	central	0.5	1	1	2	0	0.5	5	33.4	7.8	17.6	49.2
B037	F	29	7L	central	0.5	0	1	1	2	0	4.5	30.8	7.8	15.0	46.7
		29	8U	central	0	1	1	0	0	1	3	23.2	7.9	7.2	39.2

before we can achieve what we believe to be the full potential of these dental techniques of age estimation techniques.

Conclusions

The regression line and errors derived from that regression line cited by Gustafson have proved impossible to replicate despite the fact that (unusually) Gustafson published all his data. The criticisms cited by Maples and Rice have been borne out, although we differ with these authors in our interpretation of the exact data Gustafson used to derive his original regression line. The basic method used by Maples and Rice (using all of Gustafson's published data) to produce a regression line and an estimate of the associated errors has been reproduced, although we have used a slightly more rigorous approach to the estimation of errors. These estimates have been found to be systematically larger than those calculated by Maples and Rice, and are believed to be more representative of the real errors involved in the Gustafson age estimation method. This has lead us to question the error estimates of other, more recent, methods of age estimation, although this cannot be demonstrated since these authors did not publish their raw data almost certainly because of pressure on journal size in the scientific literature. There is a clear need for larger and better controlled datasets upon which to base any further refinements to these procedures.

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