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ANALYSIS

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ESTIMATION OF AGE AT DEATH USING TEETH

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Abstract. Our research is based on the confrontation of modifications of Gustafson's aging method with the aim of producing of up to date identification tables for practical anthropology. Sixty three ground sections were evaluated following the methods of Kilian and Kashyap – Koteswara Rao. Kilian's method is based on the subjective evaluation of six markers: the degree of attrition, the secondary dentine, the secondary cementum, the resorption, the transparency and the position of epithelial attachment. Future study, the evaluation of the position of epithelial attachment was not taken into account. Kashyap and Koteswara Rao's method is based on the quantitative evaluation of four markers: the abrasion, the secondary dentine, the secondary cementum and the transparency. The best results of age estimation were obtained using the Kilian's method after multiple regression of all studied changes were applied (absolute mean error of estimation 4.97 years – 95% CI ±1.00). The identification tables were produced using the mutual relationship of the sum of point values and age (absolute mean error of estimation 6.58 years – 95% CI ±1.14 years). Whenever any of the variables are not included, the error of estimation increases. These methods do not estimate the actual age in years, but only class the individuals in relatively broad categories.

Key words: *teeth*, *estimation of age*, *Gustafson's method*, *modifications*, *identification tables*

Introduction

Age estimation of an unknown person based on the examination of bodily remains can be performed either by osteological or stomatological methods. Because the teeth are frequently better preserved than other material, their use for identification of an individual's age at death is very important. Dental aging received considerable attention within the field of anthropology as well as forensic science. In children, age determination from the teeth is relatively simple and accurate; it is based on the stage of development and eruption of teeth (Komínek, Rozkovcová 1984). In adults, estimating age is more problematic. Out of many stomatological criteria the most common ones for the estimation of age at death of adult individuals involve changes in the hard tooth tissues. Gustafson was the first to devise the microscopic method for age estimation based on the histological examination of ground thin sections of teeth using a scale of 0–3 points (0; 1; 2; 3). He evalueted the extent of six changes correlated teeth with increasing age. These are: the degree of attrition (A), the position of epithelial attachment (G), the amount of secondary dentine (D), the cemental thickness (C), the degree of root resorption (R) and the transparency of root dentine (T) (Fig. 1). Their total value should correspond to a certain age. According to Gustafson the standard error of estimation for the single examination of the tooth

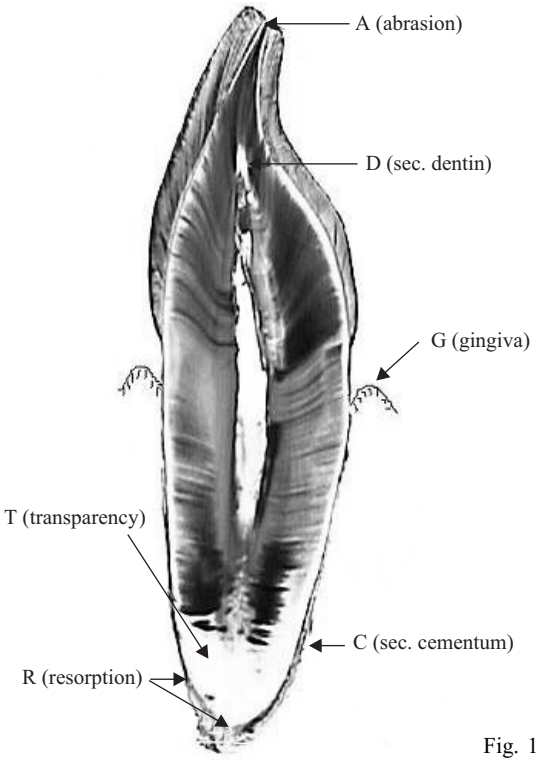

Fig. 1. Figuration of changes in hard tooth tissues

is ± 3.6 years (Gustafson 1950). However, this statement has been contested (Nkhumeleni et al. 1989; Lucy and Pollard 1995). The estimation of age performed on the basis of histological examination and evaluation of morphological changes in hard tooth tissues was believed to be one of the most reliable methods, yet it has become the subject of heavy criticism especially when used with past populations (Brůžek, Novotný 1999; Kilian et al. 1984; Vlček, Kilian 1975). Nevertheless, the principle of the histological evaluation of the changes introduced by Gustafson has become the basis for all other techniques which aim at the increase of precision of measurement (Kilian 1986; Kashyap and Koteswara Rao 1990).

Materials and methods

The dental sample was collected from October 1997 to September 1998 with the help of dental surgeries. Acquired through extractions, the teeth were consecutively disinfected by 75% ethanol, provided by tablets with number and saved in boxes with the description until the histological examination. The following information was collected: exact date of birth of the patient, date of extraction of the tooth, sex, profession, type and place of the tooth in the dentition. In total, 147 one rooted teeth from 112 individuals were collected. Because the teeth were often pathological, many could not be used, mostly because of the missing crown or root. The final number of the teeth was 63 (31 of males and 32 of females).

Ground sections were prepared at the Stomatological hospital of Charles University in Plzeň using Kilian's grinding method on an instrument of his own construction (Kilian 1975). Following grinding and dehydratation, tooth sections were embed in Solakryl BMX (*Penta*, *Prague*) between a slide and a cover glass for microscopic observation. A substantial drawback of the technique is that the tooth is practically destroyed in the process of grinding. This disadvantage can be compensated by making exact copies of the tooth, before the grinding process. The ground sections were evaluated by two modifications of Gustafson's method using the light microscope (*Olympus BX 60*) with the possibility of image analysis (*Videotip – Tescan*, *Brno*). When the research and evaluations of individual ground sections changes were performed the age, sex and profession of the individuals were not known (blind experiment).

Kilian's method is based on the evaluation of five of the six Gustafson markers. We did not score the epithelial attachment position because this evaluation is very difficult especially with the historical material (Vlček, Mrklas 1975). The individual changes were classified using a seven point scale (0, 0.5, 1, ..., 3) in the Kilian's method. We used the Kilian's atlas of the histological changes for the evaluation (Kilian 1986). In the cases, where we could not decide if the change is 1 point or 1.5 point, the change was rated as 1.25 point. The ground sections were examined four times at low magnification (faktor 3.5; larger for details). The subsequent evaluation was always performed after a certain amount of time had elapsed. Only

the last three measurements were used for the statistical evaluation and were expressed in percentages. (The maximum sum of point values regarding all five evaluated changes is 15, i.e. 100%).

Because many authors recommend to replace the subjective point classification by objective data (Xu Xiaohu et al. 1992), we performed also the evaluation after Kashyap and Koteswara Rao's method. This evaluation was performed with the use of image analysis (*Videotip – Tescan*, *Brno*). This method takes advantage of index values of various parameters of examined changes (i.e. A; D; C and T), which are calculated by relating the measured change to a fixed measurement of the tooth (Kashyap, Koteswara Rao 1990).

All the statistical analyses were performed using SPSS software package (version 6.1) and the Microsoft Excel for Windows 95 (version 7.0). The relationships between measured histological changes (or sum of point values at the Kilian's method) and age were analysed by computing the Pearson (r) and the Spearman (rs) rank correlation coefficient. Equations for age prediction were derived using least squares regression analysis. Absolute mean error of estimation was counted from absolute values of residuals (i.e. the actual value of the dependent variable minus the value predicted by the regression equation). The formulas for age prediction were also calculated from multiple regression analysis in both methods.

Results

Kilian's method evaluation

The correlation between individual histological changes and age is shown in the Table 1, 2.

The resulting formula of age calculation for relationship between sum of point values (SPV) and age using the regression analysis was established as follows:

$$AGE = \frac{SPV\% + 2.27}{1.12}$$

$r^2 = 0.84$; absolute mean error of estimation 6.58 years; 95% CI ± 1.14 (Fig. 2).

Where r^2 is the coefficient of determination, CI is the confidence interval.

Table 1

Correlation (r – Pearson correlation coeficient) between individual histological changes and age of transformed values using Kilian's evaluation

	√A	√C	√D	√R	√T
In Age	0.76	0.84	0.90	0.83	0.84

Table 2

Correlation (r – Pearson correlation coefficient) between individual histological changes and age of transformed values in the evaluation after Kashyap and Koteswara Rao's

	√Ai	lnCi	lnDi	√Ti
In Age	0.73	0.58	0.83	0.75

Xi – index value of an change, ln – natural logarithm

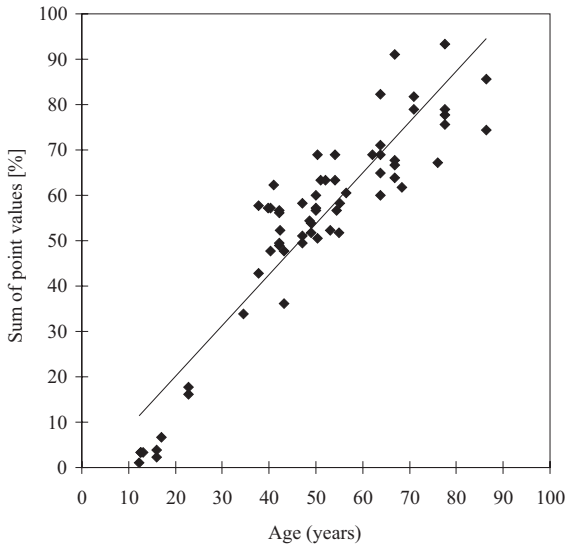

Fig. 2. A graphic expression of the relations between the sum of point values of five researched changes (attrition, secondary dentine, secondary cementum, resorption and transparency) and age

The resulting formula of age calculation for relationship between sum of point values with transparency not regarded (SPV–T) and age using the regression analysis was established as follows:

$$AGE = \frac{(SPV - T\%) + 3.42}{1.16}$$

$r^2 = 0.79$; absolute mean error of estimation 7.08 years; 95% CI ± 2.08 (Fig. 3).

Using these equations the identification tables for practical use in the field anthropology were calculated (Table 3, 4). However, the accuracy of these tables is limited to the error given about. The differences between the actual and predicted age of our sample are shown in the Table 5.

Better results of age estimation were obtained after multiple regression analysis of all five changes was applied. The formula of age estimation from all studied changes using the multiple regression analysis was obtained as follows:

$$AGE = e^{(2.47 + 0.01\sqrt{A\%} + 0.04\sqrt{C\%} + 0.06\sqrt{D\%} + 0.03\sqrt{R\%} + 0.06\sqrt{T\%})}$$

where "e" is the base of natural logarithm (ln).

$r^2 = 0.94$; absolute mean error of estimation 4.97 years; 95% CI ± 1.00.

The resulting formula of age estimation with transparency not regarded using the multiple regression analysis was established as follows:

$$AGE = e^{(2.59 + 0.02\sqrt{A\%} + 0.05\sqrt{C\%} + 0.08\sqrt{D\%} + 0.03\sqrt{R\%})}$$

$r^2 = 0.91$; absolute mean error of estimation 5.97 years; 95% CI ± 1.23.

Kashyap and Koteswara Rao's evaluation

We also run multiple regression analysis regarding all observed changes (their transformated index values) with age as dependent variable. The resulting formula of age estimation was then established as follows:

$$AGE = e^{(2.41 + 0.04\sqrt{}Ai\% + 0.20 \ln Di\% + 0.18 \ln Ci\% + 0.06\sqrt{}Ti\%)}$$

$r^2 = 0.81$; absolute mean error of estimation 8.32 years; 95% CI ± 1.61.

The resulting formula of age estimation with transparency not regarded was then established as follows:

$$AGE = e^{(2.43 + 0.06\sqrt{}Ai\% + 0.22 \ln Di\% + 0.20 \ln Ci\%)}$$

$r^2 = 0.80$; absolute mean error of estimation 8.85, 95% CI ± 1.76.

("i" is the index value of the change, for example "Ai" is the index value of the attrition, all index values were counted after formulas presented by Kashyap and Koteswara Rao in their study of 1990)

Discussion and conclusions

The teeth used in this study have been collected from different places and were extracted for many reasons. This variety of origins was considered suitable for computing the formulas for age prediction as it might better reflect the biological variation. Teeth from heterogeneous sources were used by Solheim (1993) as well.

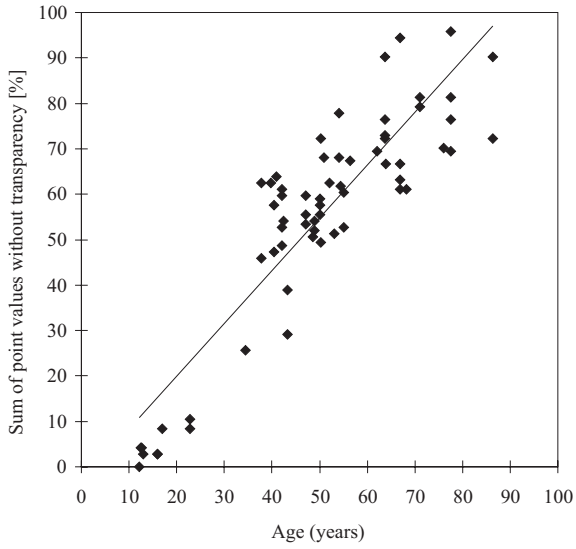

Fig. 3. A graphic expression of the relations between the sum of point values of four researched changes (attrition, secondary dentine, secondary cementum and resorption) and age

Table 3

IDENTIFICATION TABLE I (for estimation of age with the use of the subjective classification including attrition, secondary dentine, secondary cementum, resorption and transparency SPV = A + D + C + R + T)

Sum of point values	[%]	Predicted age	Sum of point values	[%]	Predicted age
0	0.00	2.02	7.75	51.67	48.09
0.25	1.67	3.51	8	53.33	49.58
0.5	3.33	4.99	8.25	55.00	51.06
0.75	5.00	6.48	8.5	56.67	52.55
1	6.67	7.97	8.75	58.33	54.03
1.25	8.33	9.45	9	60.00	55.52
1.5	10.00	10.94	9.25	61.67	57.01
1.75	11.67	12.42	9.5	63.33	58.49
2	13.33	13.91	9.75	65.00	59.98
2.25	15.00	15.40	10	66.67	61.47
2.5	16.67	16.88	10.25	68.33	62.95
2.75	18.33	18.37	10.5	70.00	64.44
3	20.00	19.85	10.75	71.67	65.92
3.25	21.67	21.34	11	73.33	67.41
3.5	23.33	22.83	11.25	75.00	68.90
3.75	25.00	24.31	11.5	76.67	70.38
4	26.67	25.80	11.75	78.33	71.87
4.25	28.33	27.29	12	80.00	73.35
4.5	30.00	28.77	12.25	81.67	74.84
4.75	31.67	30.26	12.5	83.33	76.33
5	33.33	31.74	12.75	85.00	77.81
5.25	35.00	33.23	13	86.67	79.30
5.5	36.67	34.72	13.25	88.33	80.78
5.75	38.33	36.20	13.5	90.00	82.27
6	40.00	37.69	13.75	91.67	83.76
6.25	41.67	39.17	14	93.33	85.24
6.5	43.33	40.66	14.25	95.00	86.73
6.75	45.00	42.15	14.5	96.67	88.22
7	46.67	43.63	14.75	98.33	89.70
7.25	48.33	45.12	15	100.00	91.19
7.5	50.00	46.60			

Teeth from homogeneous source, as used Maples and Rice (1979), might resulted in a stronger correlation with age, but this condition could not be keep in age estimation on an independent sample. Also for more reliable results it would be better to have the same number of teeth in all age categories. Unfortunately, our sample does not allow this.

Analysis of the data revealed that Kilian's method (absolute maximum error of estimation is 7.72 years at the 95% confidence interval) enables us to give more accurate estimations of age than Kashyap and Koteswara Rao's method (absolute maximum error of estimation is 9.94 years at the 95% confidence interval). Thus, our results do not correspond with results of original Kashyap and Koteswara Rao's

method. Other authors as well (Lopez – Nicolaz et al. 1990) failed to get more accurate results with the use of morphometric technique. One of the reasons for this lower resolution may relate to the use of four variables in the Kashyap and Koteswara Rao's method correspond to five in the Killian's method.

Our study results were similar to those using other methods (Gustafson 1950; Johanson 1971; Kilian et al. 1981). It is clear that if any of the variables are not included, the reliability of the regression model declines. From the correlation between histological changes and age, the smallest dependence was found between abrasion and age (r = 0.65) in the Kilian's method, and between cementum apposition and age (r = 0.32) in the Kashyap and Koteswara Rao's method. Abrasion is certainly affected also by other changes (as the diet) and not only by age. In the case of cementum apposition in the Kashyap and Koteswara Rao's method was the least dependence caused by not suitable way of measurement. The Kashyap and Koteswara Rao's method did not take into account the cementum apposition on the apex of the root, where the apposition is mostly largest (Fig. 4).

Table 4

IDENTIFICATION TABLE II (for estimation of age with the use of subjective point classification including attrition, secondary dentine, secondary cementum and resorption SPV = A + D + C + R)

Sum of point values	[%]	Predicted age	Sum of point values	[%]	Predicted age
0	0.00	2.94	6.25	52.08	47.72
0.25	2.08	4.73	6.5	54.17	49.51
0.5	4.17	6.52	6.75	56.25	51.30
0.75	6.25	8.31	7	58.33	53.10
1	8.33	10.10	7.25	60.42	54.89
1.25	10.42	11.90	7.5	62.50	56.68
1.5	12.50	13.69	7.75	64.58	58.47
1.75	14.58	15.48	8	66.67	60.26
2	16.67	17.27	8.25	68.75	62.05
2.25	18.75	19.06	8.5	70.83	63.84
2.5	20.83	20.85	8.75	72.92	65.64
2.75	22.92	22.64	9	75.00	67.43
3	25.00	24.43	9.25	77.08	69.22
3.25	27.09	26.23	9.5	79.17	71.01
3,5	29.17	28.02	9.75	81.25	72.80
3.75	31.25	29.81	10	83.33	74.59
4	33.33	31.60	10.25	85.42	76.38
4.25	35.42	33.39	10.5	87.50	78.18
4.5	37.50	35.18	10.75	89.58	79.97
4.75	39.58	36.97	11	91.67	81.76
5	41.67	38.77	11.25	93.75	83.55
5.25	43.75	40.56	11.5	95.83	85.34
5.5	45.83	42.35	11.75	97.92	87.13
5.75	47.92	44.14	12	100.00	88.92
6	50.00	45.93			

Table 5

The differences between actual (AA) and predicted age (PA) of our sample (for sum of point values (SPV) state the mean values from three independent evaluations)

SPV	SPV%	PA	AA	SPV	SPV%	PA	AA
0.17	1.11	3.01	12.20	8.67	57.78	53.54	37.72
0.33	2.22	4.00	16.00	8.75	58.33	54.03	47.05
0.50	3.33	4.99	12.51	8.75	58.33	54.03	55.02
0.50	3.33	4.99	12.66	9.00	60.00	55.52	50.00
0.50	3.33	4.99	13.03	9.00	60.00	55.52	63.86
0.58	3.89	5.49	16.00	9.08	60.55	56.01	56.41
1.00	6.67	7.97	17.00	9.25	61.67	57.01	68.28
2.42	16.11	16.39	22.80	9.33	62.22	57.50	41.00
2.67	17.78	17.87	22.84	9.50	63.33	58.49	50.94
5.08	33.89	32.24	34.48	9.50	63.33	58.49	52.10
5.42	36.11	34.22	43.21	9.50	63.33	58.49	54.00
6.42	42.78	40.17	37.72	9.58	63.89	58.99	66.87
7.17	47.78	44.62	40.38	9.75	65.00	59.98	63.77
7.17	47.78	44.62	43.21	10.00	66.67	61.47	66.88
7.33	48.89	45.61	42.11	10.08	67.22	61.96	75.98
7.42	49.45	46.11	42.11	10.17	67.78	62.46	66.87
7.42	49.45	46.11	47.05	10.33	68.89	63.44	50.33
7.58	50.55	47.10	50.33	10.33	68.89	63.44	54.00
7.67	51.11	47.60	47.05	10.33	68.89	63.44	62.00
7.75	51.67	48.09	49.00	10.33	68.89	63.44	63.71
7.75	51.67	48.09	55.00	10.67	71.11	65.43	63.77
7.83	52.22	48.58	42.38	11.17	74.45	68.40	86.37
7.83	52.22	48.58	53.00	11.33	75.55	69.39	77.52
8.08	53.89	50.07	49.00	11.67	77.78	71.37	77.52
8.17	54.45	50.57	48.63	11.83	78.89	72.36	71.00
8.42	56.11	52.05	42.11	11.83	78.89	72.36	77.52
8.50	56.67	52.55	42.11	12.25	81.67	74.84	71.00
8.50	56.67	52.55	50.00	12.33	82.22	75.33	63.77
8.50	56.67	52.55	54.49	12.83	85.55	78.31	86.37
8.58	57.22	53.04	39.71	13.67	91.11	83.26	66.88
8.58	57.22	53.04	40.38	14.00	93.33	85.24	77.52
8.58	57.22	53.04	50.00				

The best results of age estimation using the Kilian's method were obtained after multiple regression of all variables was applied (absolute maximum error of estimation is 4.97 years 95% CI ± 1.00). However, it is necessary to point out we calculated the absolute mean error of age estimation out of the basic sample which was used for obtaining the regression lines and formulas. We suggest that the actual absolute mean error of age estimation be calculated using a control sample of teeth in the future research.

In conclusion these methods do not estimate direct relationship with age in years but they allow us to class individuals into a set of broad age categories (in 10 or 15 years) as did also other methods of age estimation. Naturally, because of the lengthy process of preparing the ground sections and especially because of the small amount of accessible material, not all questions could be answered and

Fig. 4. Measurement of the thickness of cementum at the Kashyap and Koteswara Rao's method

ce_1, ce_2 – the thickenings of cementum at the thickest point on either side of the tooth, CE – the width of the tooth with cementum at the thickest point

not all problems of evaluation could be dealt with in full. Evidently, the issue of the estimation of age at death of adult individual's from the teeth will remain a subject of further research.

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