

Variability of a dental morphological trait

I. H. Monrad Aas

Department of Anatomy, Dental Faculty, University of Oslo, Oslo, Norway

Aas, I. H. M. Variability of a dental morphological trait. *Acta Odontol. Scand.* 1983, 41, 257–263. Oslo. ISSN 0001–6357.

A study of morphologic variability was made for maxillary incisor lingual fossa depth. The problem of variability is discussed, and new methods for the statistical treatment of variability are presented. Possibly, the best procedure to express biologic variability is to present SDs, CVs, \bar{X} s, ranges, RCs, and the logarithmic graphic method of the relationship between CV and \bar{X} . No sex differences in variability could be demonstrated. Maxillary centrals and laterals in the Eskimo were found to have relatively equal variability. This is seen in connection with the great functional demand on Eskimo incisors, giving less reduction of the laterals, a possible simultaneous commencement of calcification for I_{1sup} and I_{2sup} , and possible genetic drift. Comparison of variability for six populations shows no racial differences in variability. Variability is not found to increase with inbreeding. Population comparisons do not confirm little reduction in the Eskimo to be associated with high variability. Genetic drift might be the explanation of the homogeneity of maxillary incisor lingual fossa depth in East Greenland Eskimos. □ *Dental anthropology; incisors; statistics; variability*

I. H. Monrad Aas, Department of Anatomy, Dental Faculty, University of Oslo, P.O. Box 1052, Blindern, Oslo 3, Norway

The dental anthropological trait called shovel-shape of incisors, with well-developed lingual marginal ridges and lingual fossae, is a characteristic of the Asiatic Mongoloid race (1, 12, 25). Instead of subjective determination of the degree of shovel-shape, a method for accurate measurements of incisor lingual fossa has been used (2, 4, 14, 20–22, 27, 53).

Variability in tooth size has been studied by the coefficient of variation (CV) (8, 17, 32, 41–43). Two opposing theories, the 'clone model' (35) and the 'dental field theory' (11), both offer explanations of the differences in variability observed between teeth of the same tooth group.

The use of the standard deviation as indicator of anatomic variability has been excluded because of its positive association with the mean (23, 44, 46). Pearson & Davin (36) demonstrated a negative relationship between CV and mean value. This has later been confirmed by many others (23). The mean values should be taken into consideration in comparison of CVs (45). In several investigations comparison of variability has been carried out by graphic methods, in a co-ordinate system with $\ln \bar{X}$ on the x-axis

and $\ln CV$ on the y-axis (23). In linear measurements the logarithms of the CVs have been demonstrated to be inversely proportional to the logarithms of the means (23, 45, 49).

The CV represents the standard deviation in percentage of the mean value. The SD gives, however, little weight to tail area values. The range is also a measure of variability. Since teeth with deeper mean fossae have greater ranges in Norwegians, a correction for the differences in mean value was made in the range coefficient RC (5).

The purpose of the present study of incisor lingual fossa depth was to carry out a general discussion of morphologic variability and to present methods for the statistical treatment of the problem of variability. The aim was also to compare variabilities of six populations, of central and lateral incisors, and of males and females.

Materials and methods

The material consisted of 91 dental casts collected in 1937 from 48 female and 43 male unmixed East Greenland Eskimos (37), ear-

lier given a detailed odontological description (38). All casts used in the present study had at least one maxillary incisor lingual surface intact and free of deposits. The heavy incisal wear on lower incisors in East Greenland Eskimos made the sample sizes for lower incisors too low to be included in the study.

In 1884 the East Greenland Eskimos of Angmagssalik numbered 245 individuals. In 1937, when the present material was collected, the population amounted to 1042 individuals (in Angmagssalik and Scoresbysund together). Although some transfer from West Greenland had occurred (38), it seems reasonable to believe that at least some inbreeding was present. The life in small isolated populations of Norwegian Lapps has resulted in very high inbreeding (51). Among Finnish Skolt Lapps inbreeding is considerable (28). In both Norwegians from a suburb of Oslo (5) and Finns of Hailuoto (6) inbreeding can be considered low. The four non-Eskimo populations for whom data are given in Table 1 have been described more detailed in other investigations: Norwegian Lapps (2), Norwegians (5), Finnish Skolt Lapps (27), and Finns of Hailuoto (28).

The incisor lingual fossa was measured with a caliper with a modified end. The instrument allowed readings of 0.05 mm, but 0.1 mm was chosen as the unit of measurement. The measuring instrument and the method of measurement have been described and discussed in detail in a previous study, in which it was also shown that plaster casts are well suited for studies of lingual fossa depth (4).

Statistics

In the following, seven methods for the study of variability are given. To make it easier to identify them, they are numbered.

$$1) \quad RC = \frac{\text{Range}}{\bar{X}}$$

$$2) \quad CV = \frac{s \cdot 100}{\bar{X}}$$

3) In Fig. 1 the natural logarithms of CV and mean fossa depth have been plotted into a double logarithmic graphic system. The line of regression was calculated by the method of least squares (15) and represents the central tendency of the relationship between the natural logarithms of CV and mean. Plottings above the line of regression represent higher variability than plottings below. The method has been used to compare the coefficients of variability for measurements with different means (23, 45).

4) If the standard deviations are equal, possible population differences in CV are due to different mean values. Testing of mean values for significant differences thus also becomes a test of differences in variability. If the mean values are significantly different, a ranking of them is also a ranking of the degree of variability for the different populations.

a) A hypothesis of equal standard deviations for the six populations

$$H_0: S_1 = \dots = S_6$$

can be tested by first calculating the weighted mean for all $\ln S_i$'s (M).

Table 1. The depth of the lingual fossa (in mm) in permanent maxillary incisors of six populations

Population	I ₁ sup				I ₂ sup				Reference
	No.	\bar{X}	SD	CV	No.	\bar{X}	SD	CV	
Finns of Hailuoto	236	0.61	0.26	42.6	222	0.40	0.21	52.5	28
Finnish Skolt Lapps	173	0.54	0.27	50.0	155	0.39	0.25	64.1	27
Norwegians	224	0.51	0.25	49.4	246	0.30	0.21	69.1	5
Norwegian Lapps	142	0.44	0.29	65.8	181	0.30	0.22	72.2	2
Eskimo♂	56	0.80	0.24	29.9	75	0.60	0.21	35.5	Present study
Eskimo♀	52	0.93	0.29	30.6	87	0.71	0.24	33.4	Present study

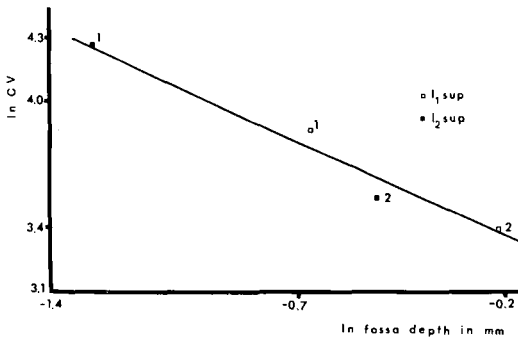


Fig. 1. Double logarithmic graphic representation of the relationship between coefficient of variation (CV) and mean lingual fossa depth for permanent maxillary incisors in male East Greenland Eskimos (2) and Norwegians (1).

$$M = \frac{1}{n - 6} \sum_{i=1}^6 (n_i - 1) (\ln S_i),$$

where $n = n_1 + \dots + n_6$ (sample size), and S_i is the standard deviation. Then Z is calculated:

$$Z = 2 \sum_{i=1}^6 (n_i - 1) [\ln S_i - M]^2.$$

If H_0 is correct, Z has a chi-square distribution (χ^2_5).

b) A hypothesis of all six populations having equal mean values:

$$H_0: \xi_1 = \dots = \xi_6$$

can be tested by:

$$F = \frac{\sum_{i=1}^6 n_i (\bar{X}_i - \bar{X})^2}{\sum_{i=1}^6 (n_i - 1) (S_i)^2} \frac{n - 6}{5},$$

which has an F distribution (15), when H_0 is correct, d.f. (degrees of freedom) 5, $n-6$.

c) When the mean values have been shown to be different, they can be ranked according to the following procedure:

$$\Pr \{(\bar{X}_i - \bar{X}_j) - \max \left(\frac{1}{\sqrt{n_i}}, \frac{1}{\sqrt{n_j}} \right) S^* \cdot q_{0.95,6,n-6}\}$$

$$< \xi_i - \xi_j < (\bar{X}_i - X_j) + \max \left(\frac{1}{\sqrt{n_i}}, \frac{1}{\sqrt{n_j}} \right)$$

$$\cdot S^* \cdot q_{0.95,6,n-6} \text{ for each pair } i, j \geq 0.95,$$

where Pr means probability, and

$$S^* = \left(\frac{\sum_{i=1}^6 (n_i - 1) (S_i)^2}{n - 6} \right)^{1/2}$$

and $q_{0.95,6,n-6}$ is the 0.95 percentile in the Studentized range (46) with 6 groups and d.f. $n-6$.

5) In the Eskimo group the data for I_{1sup} and I_{2sup} represent weighted estimates for right and left incisors. Testing of the hypothesis of equal variability for I_{1sup} and I_{2sup} in the Eskimo group

($H_0: CV_{I_1} = CV_{I_2}$) can be done by using:

$$T_1 = \frac{\sqrt{n} \ln \frac{CV_{I_2\sigma}}{CV_{I_1\sigma}}}{[1 - \hat{\rho}^2 + 2\theta^2(1 - \hat{\rho})]^{1/2}}.$$

When H_0 is correct, T_1 will be approximately standard normally distributed (15). In the equation for T_1 , n is the smallest of the two sample sizes, and

$$\hat{\theta} = \frac{1}{2} (CV_{I_1\sigma} + CV_{I_2\sigma})$$

and

$$\hat{\rho} = \frac{r_{12} + r_{13} + r_{24} + r_{34}}{2[(1 + r_{14})(1 + r_{23})]^{1/2}}.$$

In the equation for $\hat{\rho}$, r represents the correlations (Pearson's correlation coefficient) between the four incisors.

When $CV_{I_1\sigma} \neq CV_{I_2\sigma}$, then $|T_1| > 1.96$, corresponding to the 5% level as significance limit.

6) In Norwegians only right-side incisors are used, and the testing of

$$H_0: CV_{I_1} = CV_{I_2}$$

can thus be done by the following equation:

$$T_2 = \frac{\sqrt{n} \ln \frac{CV_{I_2}}{CV_{I_1}}}{[1 - \hat{\rho}_1^2 + 2\theta^2(1 - \hat{\rho}_1)]^{1/2}},$$

where $\theta = \frac{1}{2} (CV_{I_1} + CV_{I_2})$

and $\hat{\rho} = r_{12}$ (i.e. the correlation between the two incisors included).

7) Testing of the hypothesis of equal CVs for the sexes in the Eskimo group:

$$H_0: CV_{I_{1\sigma}} = CV_{I_{1\phi}}$$

can be done by practically the same method:

$$T_3 = \frac{\sqrt{n} \ln \frac{CV_{I_{1\phi}}}{CV_{I_{1\sigma}}}}{(1 + 2\hat{\theta}^2)^{\frac{1}{2}}}$$

Results

The \bar{X} s, SDs, and CVs for maxillary incisor lingual fossa depth in East Greenland Eskimos and the four other populations are given in Table 1. The ranges and RCs for the three populations for which we had access to data are presented in Table 2, representing Eskimos, Norwegians, and Norwegian Lapps.

Testing of the H_0 hypothesis of equality of the SDs, by method 4a, in the six different populations for $I_{1\text{sup}}$ and $I_{2\text{sup}}$ shows that the SDs are not significantly different. Testing of the mean values, by method 4b, for the six populations shows significant differences. The result of the ranking of the mean values, by method 4c, gives reason to claim that the order of variability for $I_{1\text{sup}}$ must be as follows: Norwegian Lapps > Norwegians > Finnish Skolt Lapps, Finns of Hailuoto > Eskimo female and male. For $I_{2\text{sup}}$ this order must be Norwegian Lapps, Norwegians > Finnish Skolt Lapps (the latter group is not significantly different from Nor-

wegian Lapps, Norwegians, or Finns of Hailuoto) > Finns of Hailuoto > Eskimo male and female. The RCs show lower variability in Eskimos than in Norwegians and Norwegian Lapps, for both $I_{1\text{sup}}$ and $I_{2\text{sup}}$ (Table 2).

Since testing of the hypothesis of equal CVs for $I_{1\text{sup}}$ and $I_{2\text{sup}}$, by methods 5 and 6, is dependent on the knowledge of the correlation coefficient, the test is performed in the two populations for which r is known. In Norwegians $I_{2\text{sup}}$ is significantly more variable than $I_{1\text{sup}}$, but not in Eskimo male and female. The RCs demonstrate that $I_{2\text{sup}}$ is more variable than $I_{1\text{sup}}$ in Eskimos, Norwegians, and Norwegian Lapps (Table 2). In Fig. 1 maxillary centrals and laterals from Norwegians and male East Greenland Eskimos have been plotted in a double logarithmic graphic representation of the relationship between CV and mean by method 3. The Eskimo $I_{2\text{sup}}$ is situated below the regression line. $I_{1\text{sup}}$ and $I_{2\text{sup}}$ in Norwegians and $I_{1\text{sup}}$ in Eskimos are situated above the line.

Testing for sex differences in the CVs in the Eskimo, by method 7, does not demonstrate any sex differences in variability. The RCs for $I_{1\text{sup}}$ and $I_{2\text{sup}}$ indicate that there are no sex differences in variability in Eskimos (Table 2).

Discussion

Variability

The positive relationship between SD and mean proposed by several authors

Table 2. Ranges and range coefficients (RC) for the depth (in mm) of the lingual fossa in maxillary incisors. The populations of Norwegians, Norwegian Lapps, and Eskimos are the same as referred to in Table 1

		Eskimo		Norwegians		Norwegian Lapps	
		RC	Range	RC	Range	RC	Range
$I_{1\text{sup}}$	♂	1.13	0.9	2.55	1.3	2.74	1.2
	♀	1.18	1.1				
$I_{2\text{sup}}$	♂	1.83	1.1	3.02	0.9	2.98	0.9
		♀	1.69				

(23, 44, 46) was not supported by the data presented in Table 1. For both $I_{1\text{sup}}$ and $I_{2\text{sup}}$ the SDs in the different populations were only slightly different, whereas the \bar{X} s were significantly different.

The CV represents the SD in percentage of the mean value and is an expression of relative variability. Between CV and the mean a negative relationship has been demonstrated (23). The graphic method with logarithmic scales also demonstrates a negative relationship between CV and mean.

With the graphic method a plot of $\ln CV$ against $\ln \bar{X}$ is equivalent to a plot of $\ln \left(\frac{100 \cdot SD}{\bar{X}} \right)$ against $\ln \bar{X}$, or $\ln 100 + \ln SD - \ln \bar{X}$ against $\ln \bar{X}$. In the present study the SD is the same for all populations. This fact reduces the value of the method of double logarithmic graphic representation of the relationship between SD and mean for the detection of population differences in variability. Since the SDs are equal, all population differences in CVs are due to differences in mean values. Testing significant differences between the \bar{X} s will thus also be a test of differences in CVs.

In the SD and CV little importance is attached to tail area values, i.e. to rare extreme biological variants. Such values are accounted for by giving the range. From a biological point of view the existence of such variants is interesting. The range and the SD are, however, not independent, and the range can be used to estimate the SD and to investigate differences between means (46). The range also has a tendency to increase with increasing sample sizes. Ideally, a comparison of ranges and RCs for different populations should be based on samples with the same sample sizes.

The question of how biological variability should be expressed can be raised. Possibly, the best procedure is to present SDs, CVs, \bar{X} s, ranges, RCs, and the logarithmic graphic method of the relationship between CV and \bar{X} . The discussion can then be carried out on that basis.

Sex differences

Garn et al. (18) found significantly greater

tooth size variation in females and concluded: 'Such a finding is in accordance with current genetic theory, if we assume that crown size is mediated by the X-chromosome in part and that additive effects will then be shown in the diploid female as contrasted with the effectively haploid male'. No sex differences in variability of lingual fossa depth of maxillary incisors were found in East Greenland Eskimos. No or small sex differences in the variability of tooth size have also been reported (8, 31, 39, 41).

An increased variability on a genetic basis in the female can be equaled or exceeded by a greater environmental influence in the male. Later tooth emergence might give increased environmental influence on crown size (19). East Greenland Eskimo females are known to use their incisors as tools to a larger degree than males. The added strength and tooth mass given by the more developed lingual marginal ridges, as shown by the deeper lingual fossa, thus becomes advantageous. This study also supports the finding of Rosenzweig & Smith (40) that variability is not greater in the females in isolated communities.

Centrals/laterals

The finding of significantly higher variability for $I_{2\text{sup}}$ than $I_{1\text{sup}}$ in Norwegians, but not in East Greenland Eskimos, illustrates the small difference in variability between centrals and laterals in the Eskimos. It is still possible that the higher RC for $I_{2\text{sup}}$ than $I_{1\text{sup}}$ in Eskimos shows a slight tendency for $I_{2\text{sup}}$ to be more variable than $I_{1\text{sup}}$.

In Fig. 1 the maxillary lateral of the male Eskimos is the only tooth found below the regression line. Exactly the same is found when the graphic representation is made with female Eskimos and with either of the right or left maxillary centrals in Norwegians, which have statistically significant mean values (5). This also points in the direction of a relatively low variability of the maxillary lateral in the present Eskimos. Pedersen (38) noted less morphologic variability of the lateral in Eskimos than in whites and much greater similarity in form and size of centrals and laterals of Eskimos.

As far as tooth size is concerned there are data suggesting that increased variability within a tooth class may be due to a larger environmental than genetic component. Estimates of heritability for the size of upper incisors have tended to be lower in the more distal teeth of each class (48). The start of enamel matrix and dentin formation of the lateral is subsequent to that of the central, but enamel formation is completed at the age of 4–5 years for both incisors (34). Corrucini (13) demonstrated variability in cusp size to be correlated with the time of the start of calcification.

No data exist for the start of calcification of maxillary incisors in East Greenland Eskimos. It may be hypothesized that the near-identical morphological variability of Eskimo centrals and laterals indicates near-simultaneous commencement of calcification.

Reduction in tooth size has been proposed to be a part of the overall phylogenetic shortening of the face (30). In a study of Greenlanders, of whom East Greenland Eskimos constituted a greater part, the degree of basal maxillary prognathism was slightly greater than in Nordic materials (29). The finding in most populations of a clearly higher variability of I_2^{sup} than I_1^{sup} is commonly seen in connection with the tendency towards reduction of I_2^{sup} .

In conclusion, East Greenland Eskimos probably have less difference in variability between centrals and laterals for lingual fossa depth than any of the other populations dealt with in this study. This phenomenon should perhaps be considered in connection with the greater functional demands on Eskimo incisors (24), resulting in less reduction (9, 26), especially of the laterals, which are known to reflect evolutionary changes more rapidly than centrals (3, 47). Genetic drift may also have resulted in the observed lack of reduction and low variability of the maxillary lateral incisor in the Eskimo population.

Population comparisons

Rosenzweig & Smith (40) could not find racial differences in variability. Although the

Eskimos, a Mongoloid population, clearly constitute the population with the lowest variability, it is doubtful that this indicates a racial difference in variability between the Mongoloids and the Caucasoids. The Eskimo population was small and lived isolated on the East Greenland coast.

Bailit (7) and Niswander & Chung (33) found variability to increase with inbreeding. In contrast, no significant differences in variability have been found between highly inbred isolated populations and more heterogeneous groups (40). In animals phenotypic variation has been shown to increase as an effect of inbreeding (10, 16). But in animal studies extremely high inbreeding can be obtained by systematic mating.

The data in Table 1 do not follow a pattern of high inbreeding–high variability. Norwegians have low inbreeding, and Norwegian Lapps high inbreeding, but both have high variability. Eskimos possibly have relatively high inbreeding, but the variability is low. Finns with low inbreeding and Finnish Skolt Lapps with high inbreeding are both medium in variability.

Frayner (17) suggested that the observed trend for reduced tooth size in European evolution is associated with a decrease of dental variation through time. This view is consistent with the findings of Suarez (50) but not with those of Wolpoff (52).

Selection has been considered the mechanism behind reduction in variability as teeth decrease in size (17). If little reduction is associated with high variability, high variability should be expected in maxillary incisor lingual fossa depth of East Greenland Eskimos. However, the variability in the Eskimo population was low, for both I_1^{sup} and I_2^{sup} , compared with the other populations in Table 1. This homogeneity of the Eskimo population might have a genetic background through genetic drift (and lack of gene flow to the population). Possibly the individual Eskimos are also exposed to a more homogeneous environment than the other populations. Pleiotropic effect can also be mentioned.

Acknowledgements.—The author thanks Professor P. O. Pedersen for giving access to his material of plaster

casts kept at the Royal Dental College, Copenhagen, Denmark, and Nils Lid Hjort, cand. real, for valuable assistance with the statistics.

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Received for publication 17 February 1982