The Use of Incisal Angles in the Steiner Cephalometric Analysis

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Incisal angles have long been recognized as useful guides in the diagnosis and treatment of malocclusion. Certain of these angles play fundamental roles in a number of cephalometric analyses e.g., those proposed by Downs,[1,2] Steiner[3,4] and Tweed[5] and it is therefore of considerable importance to determine normative values, as well as the associated ranges of normal variation about these norms, for these angles in various population groups. With respect to diagnosis, the divergence of a patient's measurements from the norms indicates the severity of the problem. For treatment, these measures relate the denture to the skeletal pattern and hence indicate the possibilities and limitations of appliance therapy.

Steiner[4] chose a set of craniofacial norms, ". . . which express our concept of a normal average American child of average age," including norms for the following incisal angles: (a) the axial inclination of the upper and lower incisors, the UI/LI angle, a measure of the degree of procumbency of the incisor teeth; Steiner set the norm at 131°, (b) the axial inclination of the upper incisor to the line from nasion to A-point, the UI/NA angle, the norm set at 22°, and (c) the axial inclination of the lower incisor to the line from nasion to B-point, the LI/NB angle, the norm set at 25°. Steiner warned the reader to, "Please bear in mind that these are rough estimates, to be used as a starting point from which to vary and must be modified by other factors . . . age, sex, race, growth potential and individual variations within these and other groupings," but provided little insight into how these modifications should be accomplished. Nor did he indicate whether or not "normal" individuals conformed to his "ideal." In this paper we investigate, using cephalometric methods, the distributions of the UI/LI, UI/NA and LI/NB angles in a large sample of "normal" individuals. The intent is to test the hypothesis that the norms proposed by Steiner are "normal," to investigate sexual dimorphism and the dependence of these angles on age, and to identify other factors which must be taken into account in order to characterize normal dentofacial morphology.

DESCRIPTION OF THE SAMPLE

The cephalograms of children presenting "normal" dental occlusion were obtained as part of a study of normal growth conducted at the Philadelphia Center for Research in Child Growth between 1948 and 1968, and were selected from a group of 2500 white elementary and secondary school children. The project director, Dr. W. M. Krogman, ". . . took in substance children who were in 'good medical health' and who had no more than rather mild so-called 'childhood illnesses' . . . 'good dental health' . . . a low DMF index . . . and all four permanent molars in place." The children selected were from what may be termed a middle-class socioeconomic group. Their ethnic distribution included Northern European (German, Scandinavian), Southern European (Italian) and Scotch, Irish and English ancestries. Middle and Eastern Europe were represented by children of Galician, Ukranian, Polish (largely Ashkenazic Jews) and Russian

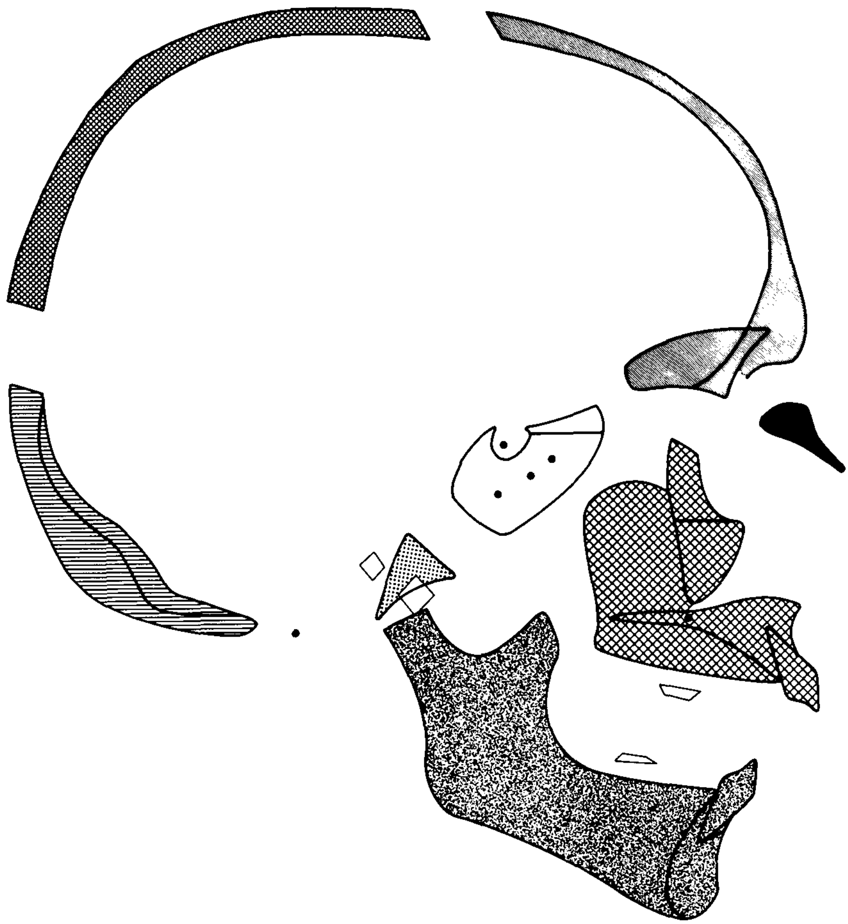

Fig. 1 The morphological structures comprising the mathematical model.

descent. In essence, those selected for the study were felt to be "reasonably representative of the [white] children of Philadelphia," during the period studied. The data to be analyzed in the present investigation are derived from the cephalograms of 1104 such individuals between the ages of six and twenty-six; 474 males and 630 females.

The Mathematical Model

The data were processed using the mathematical model of craniofacial morphology developed by Walker.[6] The roentgenographic cephalograms of the children included in the study were reduced to this mathematical model by the following procedure:

(1) The outer contours of the individual skull bones were traced by experienced technicians to produce the sagittal profile of the craniofacial complex. Figure 1 illustrates the actual structures traced and hence the components of craniofacial morphology which may be analyzed using our model.

(2) The conventional anthropometric points were marked, plus additional intermediate points to provide a sufficient number of coordinates to describe the skull contours with reason-

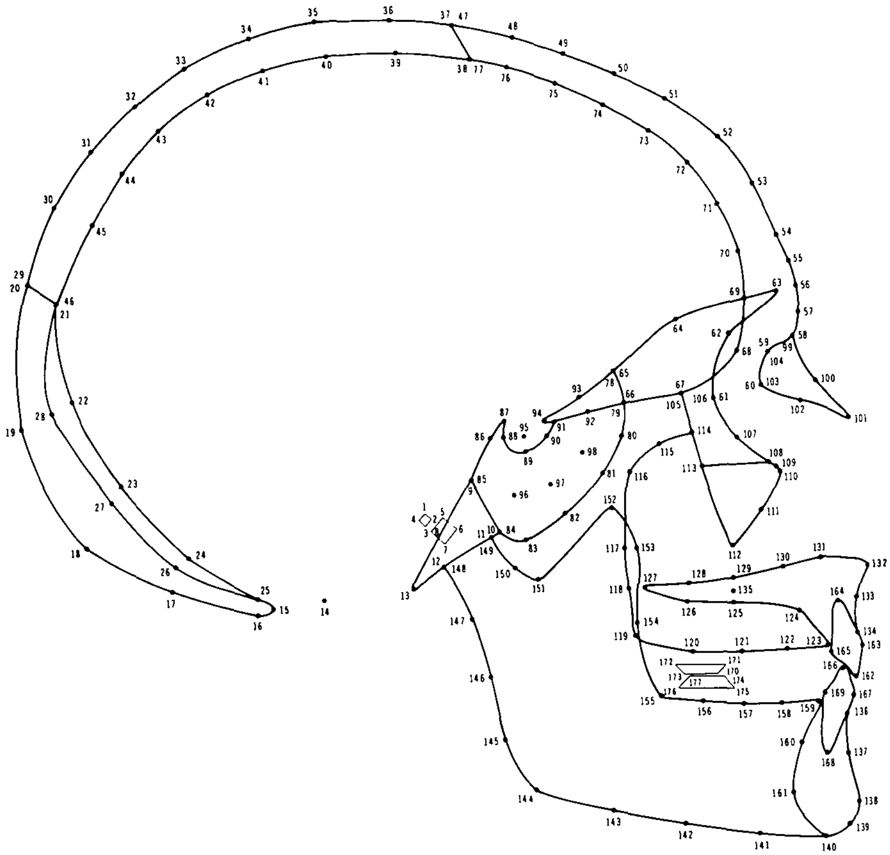

Fig. 2 The 177 coordinate points used to describe craniofacial morphology.

able fidelity. These additional points were derived by a simple geometric division of the contours into two, four or eight segments depending on the distance between the anatomical points in question. For example, the contour between lambda and bregma is relatively long and so is divided into eight segments; from menton to gonion, four segments are sufficient. In all, the model is comprised of 177 points and each point is equivalent, i.e., in the same anatomical position for each skull. Figure 2 illustrates the positions of the 177 points on the tracing of a typical cephalogram. Nasion is point #58, A-point is #133 and B-point is #137. The axis of the upper incisor is determined by the line connecting the incisal tip (point #162) with the apex (point #164); the corresponding measurement for the lower incisor is determined by the points #168 and #166.

(3) When the tracing is thus marked or "digitized," it is converted to numerical coordinates by a semiautomatic scanning process using an electronic device, such as the Benson-Lehner "OSCAR," and these coordinate values are automatically punched on IBM cards. We have found that a deck of twenty-five cards is sufficient to hold the 177 coordinate points and appropriate demographic information. This information may then be stored as cards or converted to magnetic tape and thus be available for processing on a digital computer.

TABLE 1

DESCRIPTIVE STATISTICS FOR THE UI/LI ANGLE IN 474 "NORMAL" MALES AND 630 "NORMAL" FEMALES.

	Males					Females				
Age	N	Mean	Std. Dev.	Min	Max	N	Mean	Std. Dev.	Min	Max
6- 8	21	136.3	11.860	118.8	153.0	36	139.9	10.61	122.2	158.2
8-10	73	125.2	9.405	96.55	152.3	104	125.9	6.962	101.6	141.0
10-12	114	126.5	9.297	95.59	147.9	153	126.2	7.730	111.2	147.4
12-14	124	128.0	9.670	99.38	147.6	159	128.3	8.363	110.7	158.2
14-16	85	129.6	9.924	101.0	152.7	106	129.9	8.821	112.6	158.5
16-18	35	129.7	9.190	110.2	147.7	58	129.9	10.03	114.5	153.9
18-26	22	133.7	7.602	121.8	146.2	14	133.1	7.084	117.5	146.2

An extremely rich data base can now be generated from these coordinate values; lines, planes, projections and angles are immediately available by the elementary use of coordinate geometry. Statistical analyses can then be performed on various sets of measurements of interest. While in this paper we concentrate on but three such measurements, namely, the UI/LI, UI/NA and LI/NB angles, it should be noted that the model is much more general and can be used in a variety of studies of this kind. Indeed, most of the standard cephalometric analyses are immediately available as particular subsets of the measurements which can be generated from this model. Of course, it must be realized that such analyses are no more reliable than the measurements themselves. In recognition of this, considerable care was taken with the measuring procedures employed in order to minimize the magnitudes of the measurement errors and, when possible, to obtain accurate estimates of these errors. The possible sources of measurement error, as well as our attempts to control and estimate these errors, are discussed in Walker and Kowalski *et al.*[8] We remark here only that the "acid test" of whether or not the procedure is workable in practice is to test if the recorded coordinates of the mathematical model accurately reflect the information contained in the tracing and x-ray film. This can be done by simply having the computer plot the values for comparison.[6] These plots are scaled to be comparable to the tracing and x-ray and these may be superimposed to check on the "goodness of fit." We considered the recorded coordinates as acceptable if the plot was within about .5 mm of the tracing and/or x-ray. Thus the 1104 subjects in the study were selected on the basis of having (a) "normal" occlusion and (b) accurate numerical representation in the mathematical model.

Results

The 1104 acceptable data files were stored in the memory of the computer and the UI/LI, UI/NA and LI/NB angles for each subject computed. Table 1 contains the descriptive statistics (sample sizes, means, standard deviations, minima and maxima) of the observed distribution of the UI/LI angle in the 474 males and 630 females included in the study for several age intervals. It is seen that the mean values for males and females agree

TABLE 2

DESCRIPTIVE STATISTICS FOR THE UI/NA ANGLE IN 474 "NORMAL" MALES AND 630 "NORMAL" FEMALES.

	Males					Females				
Age	N	Mean	Std. Dev.	Min	Max	N	Mean	Std. Dev.	Min	Max
6- 8	21	14.99	7.858	2.020	26.04	36	13.11	8.558	2.040	30.35
8-10	73	20.98	5.868	1.960	33.35	104	21.14	5.766	8.950	32.14
10-12	114	19.78	5.944	7.180	34.64	153	20.27	4.954	1.300	33.79
12-14	124	19.52	6.836	3.920	36.90	159	20.05	6.010	1.420	35.06
14-16	85	20.22	6.648	2.310	38.46	106	19.69	6.431	2.860	34.17
16-18	35	19.86	5.543	3.160	30.21	58	18.95	7.187	1.160	33.97
18-26	22	18.66	4.191	6.500	25.10	14	16.12	5.048	8.720	27.48

quite closely in each age group considered and thus there is no evidence of sexual dimorphism with respect to this measurement in the population studied. And while the 6-8 and 18-26 age groups have mean values significantly different ($P < 0.01$) from the mean in the intermediate age groups, it should be noted that the sample sizes in these extreme age brackets are relatively small and not of particular interest from the standpoint of orthodontic treatment. In addition, in the 6-8 year age group, another logical explanation for the observed differences is that the incisors in this age group are in, or have just completed, active eruption and have not yet found their final position. The over-all mean value of the UI/LI angle in the intermediate age groups is of the order of 129° and this differs somewhat from Steiner's ideal of 131°. Downs[1] also studied the distribution of this angle in twenty individuals having "clinically excellent occlusions," ranging from 12 to 17 years of age and about equally divided with respect to sex. He found a mean value of 135.4°, a standard deviation of 5.76° and measurements ranging from 130° to 150.5°. While it is clear that Downs' figures are based on a small sample from a rather special population, it is our feeling that the observed differences between his results and those given in Table I are probably not due so much to sampling fluctuations as they are to the difference between "excellent" and "normal" occlusion and the fact that "normality" is a multivariate phenomenon depending on proper combinations of measurements. As stated by Downs[1] ". . . single readings are not so important; what counts is the manner in which they all fit together." From this point of view the discrepancy between the two samples may be taken as a measure of the tendency of the components of the dentofacial complex to form "acceptable compromises."[4,9] We consider this point in more detail in the following section.

Table 2 gives the corresponding statistics for the UI/NA angle. Once again there is no evidence to suggest sexual dimorphism and so the sexes are probably safely pooled. The over-all mean value of the UI/NA angle in the intermediate age groups is of the order of 20° and this is somewhat smaller than Steiner's ideal of 22°.

Table 3 gives the descriptive statistics

TABLE 3

DESCRIPTIVE STATISTICS FOR THE LI/NB ANGLE IN 474 "NORMAL" MALES AND 630 "NORMAL" FEMALES

	Males					Females				
Age	N	Mean	Std. Dev.	Min	Max	N	Mean	Std. Dev.	Min	Max
6- 8	21	24.34	5.509	16.22	34.26	36	22.62	5.317	8.420	29.48
8-10	73	29.09	5.999	14.23	43.43	104	28.78	4.679	17.42	45.96
10-12	114	28.70	5.773	16.02	44.22	153	28.84	5.471	11.22	44.13
12-14	124	27.80	5.833	15.90	44.34	159	27.62	6.497	0.980	44.43
14-16	85	26.27	6.288	12.45	42.29	106	26.93	7.085	2.060	39.28
16-18	35	26.53	5.691	15.77	37.99	58	26.84	7.128	2.480	38.21
18-26	22	24.17	5.646	14.52	34.29	14	26.56	6.610	14.97	39.62

for the observed distribution of the LI/NB angle. No sexual dimorphism is in evidence and, in the intermediate age brackets, the over-all mean is of the order of 27° which is somewhat larger than Steiner's norm of 25°.

It should be noted that an individual's score on any one of these variables is related to his scores on the other variables so that an aberrant score (relative to the norm) on one variable may lead one to suspect an aberrant score on other related measures for the same individual. The extent of this interinvolvement is most usually measured in terms of the correlation coefficients between these variables, but the interpretation of these coefficients is somewhat confusing when the variables do not have joint Gaussian distributions[10,11,12] and when, as in the present case, correlations between variables may be induced purely by geometrical constraints.[13] Thus a detailed analysis of the correlation structure of these variables is not presented here. Instead, we pursue the notion of "acceptable compromises" with respect to a set of measurements for a particular individual.

Discussion

We have seen that the sample mean values of the UL/LI, UI/NA and LI/NB angles in the "normal" sample were of the order of 129°, 20° and 27° as opposed to Steiner's ideal values for these measurements of 131°, 22° and 25°, respectively. While there are differences between these sets of measurements, it is seen that the "normal" sample corresponds quite closely, on the average, to one of the "acceptable compromises" considered by Steiner. Concentrating on the dentition, Steiner studied the vector of measurements (ANB, UI-NA, UI/NA, LI-NB, LI/NB) where ANB denotes the angle formed by A-point, nasion and B-point, and where UI-NA and LI-NB denote the distances (measured in millimeters) from the upper central incisor to the line NA and from the lower incisor to the line NB, respectively. His "ideal" value for this vector of measurements is 2°, 4 mm, 22°, 4 mm, 25°, but he admitted as "acceptable compromises" the vector scores:

(4°, 2 mm, 20°, 4.5 mm, 27°)
(6°, 0 mm, 18°, 5 mm, 29°)
(8°, —2 mm, 16°, 5.5 mm, 31°).

In an earlier paper Walker and Kowalski[14] studied the distribution of the ANB angle in the "normal" population and found the average ANB angle to be approximately 4° and so it appears that the average angular measurements in this population are very close to the first "acceptable compromise," viz., (4°, 2 mm, 20°, 4.5 mm, 27°), but considerably different from Steiner's ideal of 2°, 4 mm, 22°, 4 mm, 25°. This is supported by a study of the UI-NA and LI-NB linear measurements and of the correlation coefficients between these and other variables, but a detailed presentation of these results is complicated by dependence of the linear measurements on age, sexual dimorphism and the factors alluded to earlier. It suffices to mention that the norms for the linear measurements must be modified by age and sex differences and that, when these factors are taken into account, the fit of the "normal" population to Steiner's first "acceptable compromise" is very close. As individual sets of measurements deviate from these norms, the interplay between the variables producing other "acceptable compromises" (and, on occasion, even "ideal" occlusion) is mirrored quite accurately by the correlations between the measurements involved, but a detailed analysis of the correlation structure of these geometrically and morphologically related variables is not included here.

Conclusions

We have found that "normal" dentition, as measured by certain incisal angle variables, is more accurately reflected by one of Steiner's "acceptable compromises" than by his "ideal" values for these measurements. This is an indication of the extent of the discrepancy between "normal" and "excellent" dental occlusions and also of the fact that "normality" is a multivariate phenomenon depending on proper combinations of measurements. For certain of the angular measurements these combinations may be studied without regard to age and/or sex but, in general, such modifications must be made if a battery of measurements is to accurately reflect the condition of the dentofacial complex. Tables 1, 2, and 3 also give some indication of the amount of variability to be found in "normal" populations. While it is evident that our sample is much more variable than Downs' and Steiner's, it must be remembered that the criteria used in the selection of the samples differed considerably; variability is "normal" and many "acceptable compromises" possible.

The results of this paper were obtained using a mathematical model of craniofacial morphology which may be used in a variety of contexts different from the particular study reported here. While noting that a study of this scope is only possible given an efficient medium for data processing, we also suggest that the model also has the following more general advantages:

(1) The coordinate structure contains a considerable amount of information regarding both size and shape. Indeed, given this structure, our plotting programs have allowed us to essentially reproduce the morphological structures illustrated in Figure 1. Thus the model has the advantage that, while retaining the descriptive power of the cephalogram, a numerical structure is introduced so that mathematical manipulations and statistical analyses may be applied.

(2) The model allows both numerical and visual checks to facilitate quality control of the data. We have programs that automatically "flag" extreme observations and produce plots of the suspected data file so that gross errors are easily identified and corrected.

(3) The data may be stored as punched cards or magnetic tape and so are available for rapid access by a computer. This allows on-line editing of the data bank and sequential analyses in the sense that should early results indicate the need to study more (or fewer) variables, these may be extracted and incorporated into the analysis.

(4) Statistical analyses are easily performed either on the coordinate values themselves or on derived measurements such as lengths, areas, planes, projections, angles, etc. The analyses summarized in this paper were done using CONSTAT, a console-oriented, user-prompting statistical computing program developed by the Statistical Research Laboratory at The University of Michigan for use on the IBM 360/67 via the Michigan Terminal System. Once the data are assembled in data files the appropriate measurements may be extracted and the statistical analyses done in a matter of minutes.

(5) Many of the results may be presented graphically. An important benefit is the ability of the clinician and statistician alike to view the results and interpret the observed variations as a unified whole (all the structures depicted in Figure 1 are available) in a medium which is readily understood by all.

Summary

A general mathematical model for the study of craniofacial morphology and growth was described and applied in an investigation of the distributions, in a large sample of "normal" individuals, of the incisal angle measurements proposed by Steiner. It was shown that the sample mean values of these measurements in the population studied were more accurately reflected by one of Steiner's "acceptable compromises" than by Steiner's "ideal" values for these measurements. It was also shown that the assumptions inherent in establishing normative values for these measurements irrespective of age and sex are tenable. Finally, estimates of the ranges of "normal variation" about these norms and of the relationships between these measurements and other components of the dentofacial complex were provided and discussed in the context of the theme that "normality" is a multivariate concept.

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