A Correlative Study of Winging and Certain Features of Dental Morphology in a Group of Navajo Indian Children

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A CORRELATIVE STUDY OF WINGING AND CERTAIN FEATURES OF DENTAL
MORPHOLOGY IN A GROUP OF NAVAJO INDIAN CHILDREN

By
Carl G. Gangitano

A Thesis Submitted to the Faculty of the Graduate School
of Loyola University of Chicago in Partial Fulfillment
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Master of Science

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VITA

The author, Carl George Gangitano, is the son of Salvatore Joseph Gangitano and Bessie (Klein) Gangitano. He was born on October 13, 1974, in Chicago, Illinois.

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In June, 1972, he re-entered Loyola University School of Dentistry in a two year graduate program leading to a certificate of specialty in Orthodontics.
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Appendix A.

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INTRODUCTION

Winging of incisor teeth has been variously described as "mesio-palatal torsion" (Nelson, 1937) (Leigh, 1928), "bilateral mesial rotation" (Dahlberg, Enoki, and Nakamura, 1958), and "bilateral V-shape incisors" (Wright, 1941). Since these terms are not in themselves completely descriptive, a more explicit characterization of winging that is completely consistent with the intent of the foregoing terms is herein suggested. In the following discussion the term winging is used to describe the position of the incisors when the tooth (or teeth) is rotated so that the distal surface is displaced labially and the mesial surface lingually (Figure 4). In contrast, when the mesial surface is displaced labially and the distal surface lingually, the tooth (or teeth) is in the position described as "counterwinged" by Dahlberg (1958, 1963) (Figure 3).

When anterior teeth (or a tooth) are winged or counterwinged it conveys the impression that this alignment is associated with crowding. However, Enoki and Nakamura (1958) have reported that about two thirds of the models demonstrating winging that they examined had excessive available arch space for the central incisors which suggests that local crowding may not be a prominent etiologic factor. They also found rotated teeth to be significantly smaller than teeth in normal position.

In addition, Dahlberg (1958) has described winging in crowded and uncrowded dentitions. Although he indicates that arch form and vault height no doubt influence the winged position of anterior teeth to some extent, he also considered anatomic patterns on the lingual surface, as well as genetics, as
possible etiologic factors. While he did not specifically point to shovelling as one of the contributing lingual surface patterns, there are at least two relatively well documented and reasonably well accepted observations relative to racial characteristics of the dentition that prompt an interest in a possible relationship between shovelling and winging: These are that both winging and shovelling of especially the maxillary incisors are Mongoloid traits.

The term "shovel-shape" was introduced by Muhlreiter in 1870, and applies mainly to maxillary incisors which in some populations bear a strong resemblance to a shovel due to the prominent marginal ridges and deep concavity of their lingual surfaces. Moorrees (1961) has characterized shovelling as an intensification of a morphologic trend in the evolution of the dentition, and Dahlberg (1963a) has described it as resulting from the expansion of certain ridges of the lingual surface of anterior teeth with a resulting increase in strength and mass that is decidedly advantageous to the possessor.

Dahlberg and Mikkelson (1947) report that cross sections through shovel-shaped incisors reveal that the heavy marginal ridges are not overgrowths of enamel, but consist of enamel of normal thickness with thickened underlying dentin.

Moorrees (1961) has stated that it is possible to define a basic pattern for the dentition and jaws of Mongoloids, of which shovel-shape of the maxillary incisors is one of the typical characteristics; therefore, demonstration of a relationship between shovelling and winging will help explain frequent reports of winging among Mongoloid populations. Also if this relationship can be explained on a "cause and effect basis", it would remove some of the speculation relative to: "How frequently and to what degree of expression is
shovelling found in Caucasians?" Dahlberg (1963b) has stated that the two characteristics are "seemingly associated".

Hrdlicka (1920) states that the shovel-shape occurs in both deciduous and permanent maxillary and mandibular incisors. He further states that the formation of a lingual rim and fossa (keilodonty and koilomorphy) is by no means limited to the incisors. Further examination shows that shovel-shape (pronounced lingual marginal ridges) is also common to the canines, bicuspids, and molars, albeit in reduced form. However, he also states that shovelling in man relates mainly to the upper incisors. When distinct, it is generally observed in all the four teeth, but it may predominate in one or any combination of the incisors.

In the past, the degree of shovelling has been described subjectively and metrically. Hrdlicka (1920) proposed a subjective scale for degrees of shovelling which included shovel (s) for all the better developed grades, semi-shovel (ss) for the less well developed grades, trace shovel (tr) for slight but distinct indications, and no shovel for where there was no perceptible trace of rim and fossa or where traces were so faint or imperfect so as to not deserve a special characterization (he did not suggest an abbreviation for this condition). This scale was subsequently expanded by Moorrees (1957) to a five point scale by the addition of a marked shovel category intended primarily for classifying teeth with excessively prominent marginal ridges which in a transverse section would appear to fold or roll over the lingual surface.

In an effort to eliminate the subjectivity in reports on comparative odontometry and morphology of the human dentition, a series of plaster plaques (casts) has been devised by Dahlberg (1956). Each plaque contains a number of
three-dimensional models illustrating the range of variability of various tooth characteristics and is accompanied by a brief description. The plaque P-1, "Variations of the Lingual Surface of the Maxillary Incisor Teeth," illustrates the various gradations of shovelling.

Carbonell (1963) used these plaques as an aid in her description of the frequency of shovel-shaped incisors in ten relatively homogeneous populations. She used a Boley gauge, modified as suggested by Dahlberg and Mikkelson (cited in Dahlberg, 1949), and measured the depth of the lingual fossa from a point midway between the incisal and gingival margins. Measurements of over one millimeter were considered shovel, one millimeter as semi-shovel, and less than one millimeter as trace shovel. She found a high frequency of shovelling in Mongoloid groups as compared to a low frequency in Caucasoid groups, and also examined the correlation of shovelling between the central and lateral incisors, finding highly significant positive correlations between the two teeth.

Moorrees (1957) reported a higher incidence of marked shovel shape in the maxillary lateral incisors as compared to the central incisors among the Aleuts; a finding which was supported by the findings of Carbonell (1963). No significant difference between the centrals and laterals has been reported by Bang and Hasund (1953) among the Alaskan Eskimos and by Nelson (1938) among the Pecos Indians. Dahlberg (1949) found a higher incidence of marked shovel central incisors than lateral incisors in the Pima Indians. In addition to being possible phenotypic variations between racial subgroups, the above contradictory reports of relative shovelling between central and lateral incisors are no doubt due in part to subjectivity; even when Dahlberg's plaques are used as a criterion. Variations of mesiodistal widths of centrals and laterals also
produces subjective error in estimating degree of shovelling. In addressing this problem of contradictory data, Dahlberg (1949) states: "The eventual comparison by (actual) measurement will give a reliable index."

Dahlberg and Mikkelson (1947) have reported incidence of shovelling in the Pima expressed in metric data. They measured the depth of the lingual fossa from a plane of the marginal rims with a specially modified Boley gauge. Central incisors ranged from 0.3 mm. to 2.6 mm. with a mean depth of 1.2 mm., and lateral incisors ranged from 0.1 mm. to 1.5 mm. with a mean depth of 0.73 mm. Metric data has also been reported by Goaz and Miller (1966) in a preliminary description of the dental morphology of five different tribes of Peruvian Indians. They reported a maxillary central incisor mean depth of 1.0 mm. with a range of 0.4 to 1.8 mm., and a maxillary lateral incisor mean of 0.6 mm. with a range of 0.2 to 1.3 mm. They found that almost all teeth examined in this sample showed evidence of abrasion to such a degree that the reported data is not indicative of the full extent of the characteristic in the unworn teeth. Snyder (1959) reports shovelling averaging 1.4 mm. for the maxillary central incisors and 1.3 mm. for the maxillary lateral incisors of the Point of Pines Indians.

Sexual dimorphism in shovelling has been reported by Hrdlicka (1920) and Morse (1937). Both found that pronounced shovel-shaped incisors were more frequent in females than in males in Chinese. However, Hrdlicka (1920) reports that in American Whites and Negros, and in Hawaiians the males had a greater tendency toward shovel shape than the females.

In addition to shovelling, Moorrees (1961) believes that Mongoloid populations typically exhibit relatively small differences in mesiodistal crown
diameters of maxillary central and lateral teeth. This view is disputed by Dahlberg (1973) who believes that racial subgroups show wide variability in this trait. Investigation of this disputed trait and its relation to winging and shovelling might explain how these characteristics vary between racial groups and subgroups.

Mesiodistal crown diameters have also been examined and interrelated by many investigators with the belief that a disharmony between the sizes of maxillary and mandibular teeth might affect their interdigitation and thus the overall occlusion. Since disharmonies in the ratio of the mesiodistal diameters of maxillary and mandibular teeth have been demonstrated to affect individual tooth position (Bolton, 1958, 1962), a consideration of etiologic factors of winging should include an investigation of the relationship of these measurements to winging and shovelling for each individual.

Various indices have been developed in the past for the purpose of expressing the relationships between the maxillary and mandibular tooth diameters: Such as those proposed by Bolton (1958, 1962), Lundstrom (1954), Neff (1949), and Pont (1909). Probably the most widely used index of this type in use today is that of Bolton. He has developed a tooth size analysis, including two parts, by which he determines ratios of mandibular to maxillary mesiodistal tooth diameters. By using these ratios and comparing them with standards he derived from a study of ideal occlusions, it is possible to determine which arch is deficient in mesiodistal tooth material (in relation to its opposing arch) and to what degree it is deficient. It is also possible with his technique to identify the discrepancy as being in the anterior or posterior area of the arch. Correlation of intermaxillary tooth-width ratio to winging and
shovelling may provide information explaining the differing degrees of incidence of the features that were examined in this study.

It has been reported that a trend in malocclusion exists in Mongoloid populations. Grewe, et. al. (1968) and Foster (1942) found that more class I and class II (Angle) malocclusions were seen in children with increasing percentages of Caucasian ancestry, and more class III malocclusions were seen in children of increasing Indian ancestry. In the Aleuts, Moorrees (1957) found that the most common malocclusion was of the class I type with no class II disharmonies found; aside from the class I malocclusions, all other instances of facial disharmonies and their associated malocclusions were in the class III category. Of 107 Aleuts examined, 86.8 percent were of the class I group, and the remaining 13.2 percent were in the class III group. If such a trend does indeed exist, then one might wonder if the common Mongoloid features of class III malocclusion, winging, and shovelling might be interrelated.
MATERIALS AND METHODS

Winging was analyzed in a population of 150 Navajo adolescents with an approximate age range of 10 to 18 years; all were 4/4 Navajo (or of 4/4 lineage) according to Bureau of Indian Affairs records. The dental models, poured from alginate impressions of these individuals, were gathered from a group of dental models of 875 children participating in an unrelated study. Some individuals had a mixed dentition (N=5), and some had missing permanent teeth (N=29); but the entire group had all permanent maxillary incisors present. The winging value for each maxillary incisor was determined for the 150 models of Navajo adolescents, and from this a mean winging score that is characteristic for the individual could be determined. From these individual scores a mean score that is characteristic of the group was calculated. In order to facilitate a statistical comparison of the morphologic characteristics (winging, shovelling, intermaxillary tooth-width ratios, and malocclusion types) for each individual, a second sample was separated from this larger sample which included 102 dental models with intact measureable permanent dentitions from first molar to first molar inclusive. The mean winging value for each maxillary incisor tooth was determined for this sample also, from which winging scores could be computed.

To effect a comparison between racial groups of Caucasian sample of 101 models was gathered. It consisted of models made in the Dental Hygiene Department of Loyola University School of Dentistry and of models of relatively intact dentitions from a large group of models obtained from a private practice in Joliet, Illinois. The age range of this sample was much greater than that
of the Navajo sample being from 18 to 60 years. The mean winging score, was also determined for this group and compared to the Navajo findings.

For both the Navajo and Caucasian samples the percentage distribution of positive, zero, and negative wing values was determined and graphically represented for each of the maxillary incisor teeth with the belief that this would help delineate the difference in incisor position between the two populations. In a like manner, the percentage distribution of positive, zero, and negative mean winging scores was determined and graphically represented for the Navajo and Caucasian groups.

In order to quantitatively describe winging (rotations of the maxillary incisors) it was assumed that it would be necessary to locate stable reference points which could be used to relate existing rotations to ideal incisor alignment. This would provide the capability of making objective and reproducible comparisons between individuals and population groups. These reference points would have to be relatively stable in relation to the smooth curve that would theoretically describe an ideally aligned incisor segment regardless of the size of the teeth and/or arch.

In an effort to locate such reference points, if such existed, it was initially and empirically decided to assume that a properly aligned incisor segment would describe an arc of a circle in such a manner that the incisal edges would be tangent (T) to the circle at their midpoints (M) (Figure 1). Therefore, perpendiculars (P) to these tangents (incisal edges) at the incisal midpoints (M) would represent radii of the circular arch form and would intersect at its center (C). Although it was apparent that few, if any, perfectly aligned incisor segments would describe a perfect circle, it was believed that
FIGURE 1
A THEORETICALLY IDEAL ARCH FORM
this model might provide the means of locating, or estimating the position of, a relatively stable reference point that would facilitate the quantitative description of winging and permit reproducible comparisons.

The maxillary casts to be evaluated were placed with incisal edges on the plate of a Xerox 2400 machine and a copy made. To assure that the incisal edges and their midpoints (M) would be clearly reproduced on the copy, they were carefully delineated on the casts with pencil lead. After reproduction, of a group of models with what were judged to be ideally aligned incisor segments, perpendiculars (P) to the incisal edges from the midpoints were extended palatally on the copy. While it was not expected that all these perpendiculars would intersect at a common point (C), it was observed that they bracketed (enclosed) a variably sized, but small (1-1.5 mm²), area (A) in the mid-palatal region. On examination it was observed that a line connecting the premolar interproximal spaces (I) always intersected the midline (ML) of the palate in or near this enclosed area.* (See Figure 2).

This point of intersection between I-I and ML was therefore established for this study as the reference point (C₁) from which to graphically identify the theoretical position of ideally aligned incisors (Figs. 3 and 4). To measure winging on the reproduction of the models included in this study, lines

* In the case of those models on which the perpendicular did not quite bracket point C; a re-examination of their incisor alignment, with the aid of the perpendiculars constructed on the Xerox copy, disclosed that it was not as well aligned as it was initially judged to be by visual inspection.
FIGURE 2

ESTABLISHING REFERENCE POINT C'

* An actual Xerox copy has been outlined with ink to illustrate the procedure.
were extended from this point $C^1$ through the midpoints (M) of the incisal edges. Where these lines ($C^1$-M) intersected the incisal midpoints (M), a perpendicular ($P^1$) to $C^1$-M was constructed, and these perpendiculars established the theoretically ideal position of the incisal edges tangent to the empirical ideal arch form (T) (Figs. 3 and 4). Rotation was then recorded as the angle between the reproduced (actual) incisal edge (E) and the theoretically constructed ideal position (T) (Figs. 3 and 4). Again it was empirically established that the incisal edges of teeth whose rotation Dahlberg classified as counter-winged form a negative angle with this theoretical ideal; (Fig. 3) and, conversely, the incisal edges of winged teeth form a positive angle with this "ideal" position (Fig. 4). The angle that each incisor forms with the theoretical ideal is termed a winging value, and the arithmetic sum of the four incisor angles is used to quantitatively describe the maxillary incisor winging of an individual and is recorded as the winging score. A mean winging score was also calculated for each racial group.

For the Navajo casts the degree of shovelling of the maxillary incisors was measured using two Boley gauges with vernier scales modified as suggested by Dahlberg and Mikkelson in 1946 (cited in Dahlberg, 1949). One was capable of measuring incisors of up to approximately 5.0 mm. width, and the other was used for teeth up to 6.3 mm. width. Measurements were made of the maximum lingual fossa depth of each incisor to the nearest 0.1 mm., and mean values for each of the four incisor teeth in the Navajo group were determined and compared. Also, the four measurements for each cast were added to give a shovel score which quantitatively described the degree of maxillary incisor shovelling for each individual.
FIGURE 3
COUNTERWINGING
FIGURE 4
WINGING

P' = T

15°

ML
Since shovelling and winging are both considered to be Mongoloid characteristics and involve the incisor teeth, it was decided to statistically compare the quantitative data gathered from their measurement on each individual cast for evidence of their correlation. Both traits were also examined for evidence of sexual dimorphism in their degree of expression.

The widest mesiodistal diameter for each of the maxillary and mandibular teeth from first permanent molar to first molar inclusive was measured and recorded. A Helios dial caliper with pointed tips and 0.05 mm. readout was used for the measurements. This data was used to compute the anterior and overall Bolton ratios for each individual and to determine group mean overall and anterior Bolton ratios.

The Bolton overall ratio includes all teeth from first molar to first molar inclusive, and is determined by dividing the total mesiodistal diameter of the mandibular teeth by that of the maxillary teeth. If this ratio exceeds 91.3 percent, the discrepancy is the result of relatively excessive mandibular tooth material. If the ratio is less than 91.3 percent, mandibular tooth material may be assumed to be correct, and the discrepancy is in the relatively larger maxillary teeth.

The Bolton anterior ratio is determined in a like manner by dividing the sum of the mesiodistal diameters of the maxillary six anterior teeth, from canine to canine inclusive, into the sum of the mandibular six anterior teeth. A ratio exceeding 77.2 percent denotes excess mandibular tooth material, and if the ratio is less than 77.2 percent there is excess maxillary tooth material. (See Appendix for copy of Bolton worksheet).

It was anticipated that a correlation of individual anterior and overall
Bolton ratios to winging scores, shovel scores, and malocclusion groups would provide information that might explain the differing degrees of incidence of these features.

The occlusion was assessed for each set of casts, and they were classified into the following categories according to the Angle system:

Class I
   a. ideal
   b. normal
      1. class III tendency
   c. malocclusion
      1. class III tendency
Class II division 1
   a. bilateral
   b. subdivision right
   c. subdivision left
Class II division 2
   a. bilateral
   b. subdivision right
   c. subdivision left
Class III
   a. bilateral
   b. subdivision right
   c. subdivision left
Class X

The Angle classification of malocclusion was utilized for describing the occlusion of the models since its wide usage facilitates comparison of results with the literature. In this study in order to facilitate utilization and reproducibility of the Angle classification, the following guidelines were established:

A class I occlusion is distinguished by the mesiobuccal cusp tip of the upper first molar falling between the mesiobuccal and major distobuccal cusp tips of the lower first molar. The upper canine cusp tips also must interdigitate between the cusp tips of the lower canines and first premolars. In order to classify as class I, at least three of these upper four "key" teeth
had to be in class I relation with the lower teeth. Five categories were included in the class I group: ideal, normal, normal with class III tendency, class I malocclusion, and class I malocclusion with class III tendency. Since a tendency for class III malocclusion has been reported for Mongoloid populations and because of the age range of the sample, it was decided to include "class III tendency" subcategories under the "class I normal" and "class I malocclusion" headings. This criterion is supported by the general contention that the class III growth pattern persists into the early twenties. Occlusal relationships in the class III tendency category included: end-to-end incisor relation, lower incisors in linguoversion, class III molar tendency, and buccal crossbite.

Ideal occlusion consists of all teeth being in perfect alignment and occlusion. Criteria include: perfect symmetry, absence of broken contacts, and minimal rotations. Slight mesial rotation of upper and lower incisor teeth was accepted as ideal since winging (mesial rotation) is a characteristic of Mongoloid populations.

Normal occlusion includes those casts where full orthodontic treatment is not indicated; however, minor orthodontic corrections may be desirable. Massler and Frankel (1951) found in their study that statistical analysis of the data showed that their subjective estimate of "normal" was limited to patients with less than ten malpositioned teeth. This criterion was utilized in this study.

Class I malocclusion then included all those class I casts where full orthodontic treatment was indicated. This then included cases with excessive overbite and overjet, steep curve of Spee, crowding in excess of two milli-
meters, extreme rotations, and, as stated by Massler and Frankel (1951), cases with more than ten teeth in malposition.

The class II group was defined as having the mesiobuccal cusp tip of the upper first molar anterior to the mesiobuccal cusp tip of the lower first molar. The upper canine cusp tip had to fall anterior to the cusp tip of the lower canine. A bilateral class II relation included at least three of the "key" teeth in class II relation. In cases where the class II relation existed unilaterally, subdivision categories were utilized as described by Salzmann (1957). Subdivision right and left included both the "key" teeth on the respective side in class II relation while those on the opposite side were in class I relation. The two general categories of class II malocclusion are class II division 1 and class II division 2, and are distinguished primarily by the positions of the maxillary incisors. The class II division 1 category is described as having the upper anteriors in normoverison or labioversion, while the class II division 2 generally has the maxillary central incisors in excessive lingual inclination and the maxillary lateral incisors in excessive labial inclination. In class II division 2 malocclusion some variation occurs in maxillary incisor positions, and all or any combination of incisors may be in linguoverison as stated by Graber (1966).

A class III malocclusion was indicated by the mesiobuccal cusp tip of the upper permanent molar bilaterally occluding distally to the major distobuccal cusp tip of the lower molar irrespective of canine relation. Right and left subdivision class III malocclusions would have a class III molar relation on one side and a class I relation on the opposite side.

An X classification was included to contain those models with unshed
deciduous teeth, missing permanent teeth, and those models which could not be
categorized according to the above criteria. In determining the distribution
of the various types of occlusion for comparison with the literature, the X
category was deleted, and only the 102 casts with intact permanent dentition
from first molar to first molar inclusive were used.

In order to aid classification, pencil lines were scribed from the cusp
tips gingivally along the prominences of the labial or buccal surfaces of the
permanent canines and first molars. During classification these reference
marks were viewed from a point relatively perpendicular to the respective
buccal segment when checking interdigitation of the teeth. Two second-year
orthodontic graduate students participated in categorizing the casts, and any
questionable casts were discussed and agreement reached as to their categori-
zation.
RESULTS

Winging

The entire sample of dental models of 150 Navajo adolescents was analyzed for winging utilizing Xerox copies of the marked maxillary casts. The group had a mean winging score of +33.02° (N=150, S.D.=23.52, and range -29° to +91°). Sexual dimorphism was evident since the female mean wing score of +27.25° (N=52, S.D.=23.17, and range -29° to +72°) was significantly different than the male mean wing score of +36.27° (N=98, S.D.=23.26, and range -30° to +91°) at the p < .05 level.

The second smaller group of 102 models with intact and measureable permanent dentitions from first molar to first molar inclusive had a mean winging score of +35.45° (N=102, S.D.=21.42, and range -9° to +88°). Sexual dimorphism was not apparent in this group, since the females had a mean winging score of +30.78° (N=37, S.D.=20.51, and range -9° to +72°) and the males a score of +38.11° (N=65, S.D.=21.62, and range -21° to +88°).

The Caucasian mean winging score was +0.41° (N=101, S.D.=24.01, and range -52° to +51°). Sexual dimorphism was not evident in this sample either; the female mean winging score was -2.92° (N=52, S.D.=24.18, and range -52° to +51°) and the male was +3.94° (N=49, S.D.=23.58, and range -48° to +48°).

Comparison of the Navajo mean wing score of +35.45° (N=102, S.D.=21.42) with the Caucasian mean wing score of +0.41° (N=101, S.D.=24.01) revealed a highly significant difference at the p < .01 level.

The distribution of positive, zero, and negative mean wing scores for the Navajo sample of 150 casts was 92.7% positive, 7.3% negative, with no zero mean.
wing scores. For the Caucasian sample (101) there were 55% positive, 1% zero, and 45% negative wing scores. (Table 1, Figure 5).

The distribution of positive, zero, and negative wing values for each of the maxillary incisor teeth was also determined for the two samples. (Table 2, Figure 6).

**Shovelling**

For the Navajo the mean shovel values for each of the four maxillary incisors were 0.75 mm. and 0.73 mm. for the right and left lateral incisors respectively; and the right and left central incisors both had mean shovel values of 1.21 mm. There was a highly significant difference between the central and lateral shovel values (p < .01). The mean central incisor shovel value is 1.21 mm. (N=227, S.D.=0.35, range 0.3 to 2.9 mm.), and the mean lateral incisor shovel value is 0.74 mm. (N=213, S.D.=0.26, and range 0.2 to 1.5 mm.).

The mean shovel score for all the maxillary incisors in the group was 3.86 mm. (N=102, S.D.=0.99, and range 1.4 to 7.3 mm.). Sexual dimorphism for the shovel characteristic in the Navajo was not statistically identifiable; the female mean shovel score was 3.95 mm. (N=37, S.D.=1.07, and range 2.0 to 7.3 mm.) and the male mean shovel score was 3.82 mm. (N=65, S.D.=0.95, and range 1.4 to 6.5 mm.).

Statistical examination of the quantitative data concerning shovelling and winging scores in both Navajo samples failed to reveal significant correlation between the expression of these two morphologic features. In addition, the statistical comparison of the individual wing value, shovel value, and mesiodistal width of maxillary right central incisors failed to demonstrate a significant correlation between these features.
TABLE 1
OVERALL WING SCORE DISTRIBUTION

<table>
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<tr>
<th></th>
<th>Caucasian (N=101)</th>
<th>Nevajo (N=150)</th>
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<tr>
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<td>zero</td>
</tr>
<tr>
<td>N</td>
<td>55</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>55%</td>
<td>1%</td>
</tr>
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</table>
FIGURE 5

OVERALL WING SCORE DISTRIBUTION

N: Navajo
C: Caucasian

PERCENT

POSITIVE  ZERO  NEGATIVE

SCORE
### TABLE 2

**INCISOR WINGING VALUE DISTRIBUTION**

**Navajo (N=150)**

<table>
<thead>
<tr>
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<tr>
<td>N</td>
<td>114</td>
<td>7</td>
<td>29</td>
<td>134</td>
</tr>
<tr>
<td>%</td>
<td>76%</td>
<td>4.7%</td>
<td>19.3%</td>
<td>89.3%</td>
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</table>

**Caucasian (N=101)**

<table>
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<th>Right Lateral</th>
<th>Right Central</th>
<th>Left Central</th>
<th>Left Lateral</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>N</td>
<td>40</td>
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<td>52</td>
<td>54</td>
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<tr>
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<td>39.6%</td>
<td>8.9%</td>
<td>51.5%</td>
<td>53.5%</td>
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</tbody>
</table>
FIGURE 6

INCISOR WINGING VALUE DISTRIBUTION
N: NAVAJO    C: CAUCASIAN

PERCENT

VALUE

+: N C N C
0: C N N N
-: C C N N

+/0/-

100 90 80 70 60 50 40 30 20 10 0
Intermaxillary Tooth-Width Ratios

The mean Bolton overall ratio for the Navajo sample is 91.78 (N=112, S.D.=2.87, and range 76.94 to 103.81). The mean Bolton anterior ratio for this sample is 79.05 (N=112, S.D.=3.60, and range 64.47 to 93.64).

Statistical comparison of the Navajo mean overall Bolton ratio of 91.78 and the Caucasian ideal established by Bolton of 91.3 (N=55, S.D.=1.91, and range 87.5 to 94.8) showed no significant difference. However, there was a significant difference (p<.01) between the Navajo mean anterior ratio of 79.05 and the Caucasian Bolton anterior ratio norm of 77.2 (N=55, S.D.=1.65, and range 74.5 to 80.4).

Comparison of the Navajo overall Bolton mean with that established by Lundstrom (1954) of 92.3 (N=63, S.D.=2.07) revealed no significant difference. Likewise, there was no significant difference between the Navajo anterior ratio mean and the Lundstrom anterior ratio mean of 78.5 (N=264, S.D.=2.07).

Statistical examination failed to show significant correlation between individual winging scores and either the anterior Bolton ratios or overall Bolton ratios.

Malocclusion Distribution

The models of the 150 Navajo were separated into categories according to type of occlusion. (Table 3). The class X category contained 29 models; however, it has been deleted from the tables to facilitate comparison of results of the study with literature.

A comparison of the distribution of the types of occlusion in this study to those reported in the literature is shown in Table 3. The categories and percentage distributions are presented in the left columns while the per-
<table>
<thead>
<tr>
<th>Investigator</th>
<th>Present Study</th>
<th>Massler</th>
<th>Ast</th>
<th>Grewe</th>
<th>Wood</th>
<th>Moorrees</th>
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<tr>
<td>Racial Group</td>
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<td>Aleut</td>
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**Class I**

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<tr>
<td>Ideal</td>
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<td>2.93</td>
<td>4.7%</td>
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<td>↑</td>
<td>86%</td>
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<tr>
<td>Normal</td>
<td>30.17</td>
<td>18.23</td>
<td>↑</td>
<td>34.6%</td>
<td>18%</td>
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<tr>
<td>III tend.</td>
<td>5.17</td>
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<td>↓</td>
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<tr>
<td>Malocclusion</td>
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<tr>
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**Class II/1**

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**Class II/2**

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<td>1.6</td>
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<td></td>
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<tr>
<td>Subdivision L</td>
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**Class III**

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<tr>
<td>Bilateral</td>
<td>0.86</td>
<td>9.4</td>
<td>1.6</td>
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<td>Subdivision L</td>
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<td>↓</td>
<td>↓</td>
<td>↓</td>
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percentage figures from reported studies are placed in the rows opposite the best category to which they correspond. When more than one category is best represented by reported figures, arrows are extended from these figures to include all inclusive categories.

Statistical comparison utilizing chi-square distribution of the reports in the literature on incidence of malocclusion showed that the Navajo group studied distributed differently than all groups to which it was compared.

With the assumption that tooth morphology may affect the distribution of types of malocclusion, the quantitative data on tooth morphology (wringing, shovelling, anterior ratio, and overall ratio) was examined for evidence of clustering into certain categories of occlusion. Statistical examination of the data by analysis of variance failed to reveal any evidence of an association between any type of malocclusion and morphology or rotation of anterior teeth.
DISCUSSION

Winging

When the quantitative measurements of winging were examined for evidence of sexual dimorphism a significant difference was noted with the larger Navajo sample but not in the smaller Navajo sample. In the smaller (N=102) sample the t value approached that of significance at the p<.05 level, but the failure to detect significance was no doubt due in part to the smaller N of this sample and the relatively large standard deviations for winging. Additionally, the difference between the means was also slightly smaller for the smaller sample: 7.33° as compared to 9.02° in the larger group.

The larger Navajo sample (N=150) had greater variability in winging than the smaller sample with complete dentitions. The difference between the female and male winging scores was larger; both female and male standard deviations were larger; and the group standard deviation was also larger. The primary morphologic differences between the two samples were that the larger sample contained 29 casts with missing teeth and 5 casts with one or more deciduous second molars present. Loss of integrity of the dental arches due to loss of teeth, and the ensuing drifting of dental units causes broken contacts and changes in occlusion which may secondarily cause increased rotations (winging) and variability, since proper contacts are thought to help prevent rotation by supplying bracing of the teeth. Loss of posterior teeth also usually causes an increase in the curve of Spee and deepening of the overbite. The concomitant occlusal changes may then interact with the heavy lingual marginal ridges of
the maxillary incisors (resulting in greater occlusal interaction between the maxillary and mandibular incisors) to affect increased winging. While there was a marked difference in the degree of winging between the Navajo and Caucasians, the Caucasian sample which has a mean winging score of +0.41° failed to show statistical evidence of sexual dimorphism when comparing the female mean winging score of -2.92° and the male mean winging score of +3.94°. However, the difference in the Caucasian female and male means of 6.86 approached that seen in the Navajo groups of 9.02 (N=150) and 7.33 (N=102), and was consistent with the males showing a greater positive rotation (winging) than the females. The variation of the trait's expression was also similar in the group of Caucasians and Navajo as evidenced by the similar standard deviations of 24.01 and 23.52 respectively. In both groups the males had a relatively more positive mean winging score than the females.

The observation of greater positive rotation in the male is consistent with a technique commonly taught in the prosthodontics laboratory for sexual characterization of denture "setups", where the maxillary lateral incisors are rotated distally (counterwinged) to "soften" the denture "setup" and make it more feminine.

Statistical comparison of the Caucasian mean wing score of +0.41° with the Navajo mean wing score of +35.45° revealed a highly significant difference (p < .01). This finding is consistent with Dahlberg's (1958) report comparing winging and counterwinging in his own study of Indian tribes and Chicago Whites. He reports the incidence of bilateral winging as ranging from 22% to 38% among Indian tribes, but dropping to 3% for Chicago Whites. One might expect that his data would most likely yield a relatively more positive mean
winging score for the Indians if they had been evaluated by the method employed here. Conversely, he reports the incidence of bilateral counterwinging as ranging from 3% to 28% in Indian tribes and rising to 42% for Chicago Whites, which would probably yield a relatively more negative mean winging score for the Caucasians. It is difficult to compare the methods and results of the present study with that of Dahlberg, Enoki, and Nakamura, since it is published in Japanese; however, the graphs and summary are in English.

In order to better demonstrate the difference in winging between the Navajo and Caucasian samples, the data has been presented as a percentage distribution of the occurrence of positive, zero, and negative incisor wing values and mean wing scores in each population. (See Tables 1 and 2, Figures 5 and 6) Since a mean wing score may involve summation of positive and negative incisor wing values which cancel each other within and between individuals, it was thought that this display of the data might better characterize the two populations. The percentage distribution of winging scores in the Caucasian population (N=101) is 55% positive, 1% zero, and 45% negative. For the Navajo (N=150) it is 92.7% positive, 0% zero, and 7.3% negative. This data is again consistent with that reported by Dahlberg (1958), where interpretation showed that incisor rotation in the Indians was relatively more positive than in the Caucasians. He also reported the incidence of counterwinging in Chicago Whites as 42%, which is consistent with the 44.5% incidence of negative wing scores for Caucasians in this study of another group of Chicago Whites.

In comparing the incisor wing values, the Navajo show more positive rotation for each tooth than the Caucasians. In contrast, the Caucasians show more negative rotations for each tooth than the Navajo. (See Table 2 and
Figure 6). This data suggests that positive rotation is more characteristic of the Navajo and negative rotation of the Caucasians. It is also interesting to note that in both the Caucasians and Mongoloids the central incisors show the greatest tendency to be winged, while in both races the lateral incisors are more counterwinged than the central incisors. This observation suggests that there may well be similar circumstances in both groups that are in part responsible for winging and counterwinging, and at the same time there may be a unique influence in each group accounting for intergroup differences.

A theoretically ideal arch should yield a zero wing score, which is remarkably close to the +0.41 mean winging score for the Caucasian sample. While only 1 percent of this sample shows a zero mean winging score, the remaining scores distribute almost equally in the positive (55%) and negative (45%) categories; whereas the positive mean winging scores dominate in the Navajo sample (92.6% positive and 7.4% negative) as would be expected in a population demonstrating winging. Thus we see that the Caucasian sample varies on either side of the theoretical ideal, while the Navajo sample shows a predominance of positive rotations (winging).

In testing the sensitivity of this method for measuring rotations it was found that this procedure was more sensitive than a casual visual evaluation of rotations. Initially, a number of models were selected for having ideally aligned arches. Copies were made of each, and the wing values were determined for each maxillary incisor. Upon examination of the wing values it became apparent that some of the incisors were in reality not ideally aligned, but had slight rotations.

It was observed that a brachycephalic individual would have relatively
higher positive incisor wing values than a dolichocephalic individual. This is due to the fact that as the arch form becomes broader (more brachycephalic), the reference point $C^1$ will be moved relatively closer to the incisors causing the theoretically ideal incisor position $(P^1,T)$ to be more counterwinged in relation to the actual incisor position $(E)$, (See Figure 4) thus resulting in a relatively more positive winging value. The Navajo sample studied was primarily brachycephalic, which further contributed to the findings of predominantly positive rotations.

**Shovelling**

Moorrees (1957) has stated that the shovel-shaped incisor is not only a seemingly valuable trait for singling out Mongoloid populations, but it may also be of additional value in determining interpopulation differences. Hrdlicka (1920) has demonstrated the variability of occurrence of this characteristic between populations. He has shown a rise in occurrence of well developed shovel-shaped upper incisors to range from an almost insignificant occurrence in white Americans to almost universal occurrence in American Indians, with American Blacks, Hawaiians, Chinese, and Japanese falling between in increasing order of frequency. This data was accumulated utilizing his subjective evaluation of the trait.

A comparison of the reported metric data shows a remarkable similarity among the populations studied. Comparison of the Navajo mean shovel values of 1.21 mm. for central incisors and 0.74 mm. for lateral incisors with those reported by Dahlberg and Mikkelson (1947) for the Pima of 1.2 mm. and 0.73 mm. respectively, reveals almost identical values. Comparison of the Navajo values to those reported by Goaz and Miller (1966) in Peruvian Indians of 1.0 mm. and
0.6 mm. revealed that these were also quite similar, especially when the abrasion in the Peruvian Indian sample is considered. The only sample which showed a great discrepancy with the Navajo was that of Snyder (1959) of the Point of Pines Indians. In this sample the central mean shovel value of 1.4 mm. was similar although larger than the Navajo (1.21 mm.), but the lateral mean shovel value of 1.3 mm. was much larger than that of the Navajo and, indeed, even larger than the Navajo central incisor value. All of the studies reporting metric data for shovelling showed a greater depth of lingual fossa for the centrals than the laterals. Except for the Point of Pines group, which showed similar means*, the difference between the centrals and laterals is similar: 0.47 for the Navajo, 0.47 for the Pima, and 0.4 for the Peruvian samples (See Table 4). These results would not support Moorrees' (1957) belief that the shovel trait may be of value in determining interpopulation differences, and are inconsistent with Moorrees' (1957) and Carbonell's (1963) findings of higher incidence of marked shovel in lateral incisors than in central incisors. The fact that they used subjective methods for determining the degree of shovelling may, in part, explain this difference. It may well be that in the case of a lateral and central incisor with fossae of equal depth, the smaller lateral may appear more shovelled.

When one compares the interracial differences in the winging data to Carbonell's (1963) findings that shovel-shaped incisors are present in varying

*It is interesting to point out that the Point of Pines Indians which have such marked shovelling on the lingual, were also found to have extensive double shovel-shaped incisors.
<table>
<thead>
<tr>
<th>Study</th>
<th>Racial Group</th>
<th>Centrals</th>
<th>Laterals</th>
<th>Difference</th>
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<tr>
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<td>Navajo</td>
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<td>0.74mm.</td>
<td>0.47mm.</td>
</tr>
<tr>
<td>Dahlberg &amp;</td>
<td>Pima</td>
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<td>0.74</td>
<td>0.47</td>
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<td></td>
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<tr>
<td>Goaz &amp; Miller</td>
<td>Peruvian</td>
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<td>1.4</td>
<td>1.3</td>
<td>0.1</td>
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</table>
frequencies among the groups she studied, it becomes apparent that there may be a correlation between the two morphologic traits. Carbonell (1963) found that there is a definite range in the frequency of shovel-shaped incisors in Mongoloid and non-Mongoloid groups, and that a high frequency of shovel-shaped incisors is found in groups with Mongoloid affinities, as compared to a low frequency of shovel-shaped incisors in Caucasoid groups. This distribution compares to the findings in this study that the incidence of positive incisor wing values is greater in the Navajo as compared to a higher incidence of negative incisor wing values in the Caucasian sample (See Figure 6). These findings prompted statistical comparison of the data from the quantitative measurement of winging and shovelling in this study for evidence of statistical correlation. The data of this study failed to show significant correlation between these morphologic features when comparing individual incisor wing values and shovel values, and wing scores and shovel scores. In spite of these negative findings, one cannot escape the conclusion that these characteristics are related, since they both frequently occur in the same population, and involve the same section of the dentition. It may be that the narrow range of shovelling (0.2 to 2.9 mm.) and the wide variability of winging account for the failure to demonstrate a correlation of these features.

**Intemaxillary Tooth-Width Ratios**

Comparison of the Navajo group mean intermaxillary tooth-width ratios with the norms established by Bolton for a Caucasian sample revealed no significant difference between the overall Navajo group mean of 91.78 and the Bolton norm of 91.3 (N=55, S.D.=1.91, and range 87.5 to 94.8). There was a significant difference between the anterior Navajo group mean of 79.05 and Bolton norm
of 77.2 (N=55, S.D.=1.65, and range 74.5 to 80.4), at the p < .01 level. This is an interesting finding since it identified an interracial difference in intermaxillary tooth width ratio in the Navajo anterior segment where winging and shovelling are also present. However, the two samples are somewhat disparate since Bolton's Caucasian sample was of 55 excellent occlusions (44 orthodontically treated non-extraction cases and 11 untreated cases), and the Navajo group (N=112) consists of a random sample.

To better determine if a difference exists between the Caucasian and Navajo anterior ratios, the Navajo group means were compared to those derived by Lundstrom (1954) in his study of a random sample of occlusions of European schoolchildren. Statistical comparison of the Navajo group mean overall ratio of 91.78 with that of Lundstrom of 92.3 (N=63, S.D.=2.07, and range 88 to 97.5) revealed no significant difference. Comparison of the Navajo anterior ratio of 79.05 with that of Lundstrom of 78.5 (N=264, S.D.=2.07, and range 73 to 84.5) also revealed no significant difference, although the t value approached that of significance. Since Lundstrom's Caucasian sample is unselected, this is a more valid comparison; and we must therefore conclude that there is not a significant difference in intermaxillary tooth width ratios between the Caucasians and Navajo.

In comparing the findings of the various studies of winging it becomes apparent that the mesiodistal dimensions of the teeth do not seem to play an important role in its etiology. The findings of no significant interracial difference in the intermaxillary tooth-width ratios is consistent with these conclusions, as is the observation of Dahlberg (1958) that winging occurs in both crowded and uncrowded dentitions. Enoki and Nakamura (1958) investigated
the relationship of various "width" factors such as the width of incisors, space available for incisors, coronal and basal arch width, and facial width (bzygomatic and bicondylar) to winging, and found no positive relationships between these factors and this phenotype. Also, in this study of the Navajo, the width of maxillary right central was not related to winging.

In order to further test the possibility of the variation of the mesiodistal dimensions of the teeth being an etiologic factor in winging, a statistical test for correlation was undertaken to compare individual winging scores to the individual's anterior and overall Bolton ratios. The findings failed to show any evidence of a consistent variation between winging scores and the intermaxillary tooth width ratios.

It would seem that the labiolingual dimensions of the teeth may play an important role in the etiology of winging, especially in consideration of the evidence presented against that of the mesiodistal dimensions. The association of shovelling, which affects the labiolingual dimension of the incisors, with winging also lends credance to this hypothesis. It has been speculated by Dahlberg (1958) that the anatomy of the lingual surface of the incisors may play a role in the variability of expression of winging. In fact, occlusal forces of the lower incisors against the lingual surfaces of shovel-shaped upper incisors might be thought to account for winging except for the fact that observation of a large number (N=150) of casts failed to support this belief. It was observed that the lingual marginal ridges of winged incisors did not generally occlude with the lower teeth in such a manner that forces of occlusion would have caused their mesial rotation.

Observation of the position of erupting incisors on dental models of
Indian children revealed that the incisors were in the winged positions as they emerged through the mucosa and before they reached occlusion. Also, the shovel feature is apparent in the incisor germs before calcification is initiated. (Kraus, 1965). For this reason it is thought that the shovel-shape of the incisors may play its role in the etiology of winging during the development of the incisors in their crypts. The positions of the developing maxillary central and lateral incisors in the crypts during tooth development as described by P. R. Begg in his orthodontic textbook (1971) seems to support this proposal. The lateral incisors are situated lingual to the distal marginal ridges of the developing central incisors so that increased prominence of the central incisors' marginal ridges would cause all four incisors to be situated in a mesially rotated (winged) position in the crypts. (See Figure 7).

Limitations of the Angle system were recognized as the study proceeded, and have been discussed by many authors such as Massler and Frankel (1951), Ast, Carlos and Cons (1965), and Salzman (1965); but, nevertheless, it continues in wide acceptance. The primary criticism of the Angle system is that it is qualitative rather than quantitative: It segregates occlusions into relatively few classes which include an infinite number of phenotypic variations. For this reason it is sometimes difficult to make distinct differentiations between the classes of occlusion.

Separation of the casts (N=116) into categories of occlusion was done in order to compare the distribution of malocclusion in the Navajo with reports in the literature (See Table 3). It was compared (See Table 3) to Massler and Frankel's (1951) group of 2758 Chicago Whites, Ast's (1965) group of 1413 New York high school children, Grewe's (1968) group of 651 Chippewa, Wood's (1971)
FIGURE 7

POSITION OF DEVELOPING INCISORS
group of 100 Eskimo, and Moorrees' (1957) group of 107 Aleuts. These comparisons revealed that the Navajo in this study distributed differently than all groups to which they were compared. The relative absence of class III malocclusions (0.86%) in the Navajo and high occurrence of class II malocclusions (26.74%) is noteworthy since Mongoloid populations have been previously reported to have a higher incidence of class III malocclusions than Caucasians. Initially, it was thought that the age range of the sample might be influencing the number of class III malocclusions observed, since the class III growth pattern sometimes manifests itself in late adolescence or early adulthood. For this reason, the class III tendency subcategories were included. When incidences of these categories (5.17% and 6.03%) are totaled with the class III category (0.86%) to obtain 12.06%, a value approaching that of Moorrees' value of 14% for the Aleuts is reached; however, Moorrees (1957) reported zero incidence of class II malocclusions in the Aleut population with an age range of 11 to 70 years as compared to 26.74 percent in the Navajo. The younger age ranged of Grewe's (1968) Chippewa sample (9 to 14 years) and Wood's (1971) Eskimo sample (11 to 18 years) is similar enough to that of the Navajo (10 to 18 years) not to warrant summation of these categories.

If one considers that rotated (winged) maxillary incisors have a smaller effective mesiodistal width than regularly aligned incisors, one might hypothesize an anterior drift of buccal segments with resulting class II tendency in Mongoloid populations which "normally" exhibit winging. Additionally, the prominent lingual marginal ridges of the crowns of maxillary incisors associated with shovelling may have initially had a tendency to cause anterior displacement of the maxillary incisors due to occlusion, which might allow
anterior drift of the buccal segments and a tendency toward a class II occlusion. This hypothesis is supported by the results of this study which show the Navajo to have a greater incidence of class II malocclusion (26.74%) than either Massler's (19.39%) or Ast's (9.7%) Caucasian groups where winging is not an expected finding. Results reported for other Mongoloid groups do not support this hypothesis since they all report a similar or smaller incidence of class II malocclusions than the Caucasian groups (See Table 3); and, conversely, report a similar or higher incidence of class III malocclusions than the Navajo.

As a further test of the possibility that morphologic features might affect occlusion, a statistical test (analysis of variance) was used to discern if those morphologic features measured in this study tended to group or "cluster" into a category of occlusion. Winging scores, shovel scores, anterior Bolton ratios, and overall Bolton ratios were all statistically examined for this possibility, with the finding that there was no significant difference between the categories of occlusion for the incidence of these characteristics. Probably an overriding influencing factor to the contradictory data presented here is the fact that the Angle classification is inadequate, and until there is a more quantitative system of categorizing malocclusions, it will be difficult to study their etiology and relate quantitative data to their classification.
An effort has been made to quantify one aspect of dental morphology, winging, in order to facilitate reproducible and meaningful studies. Employing a technique, described here, to quantitatively describe the degree of winging, this dental characteristic and shovelling, intermaxillary tooth-width ratios, and malocclusions were examined for evidence of correlation in an attempt to identify factors responsible for winging. In general it was observed that there was no apparent relationship between these dental features in a Mongoloid group. While it was found that there is a marked difference between a Navajo and Caucasian group in the extent and character of winging, it was observed that the intragroup variation in the expression of this feature is quite similar.

Information gathered from this investigation suggests that genetic factors act before eruption to cause the incisors to assume a winged (mesially rotated) position. These factors are probably mediated through the associated morphologic feature of shovelling in producing winging.
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ANALYSIS OF TOOTH SIZE DISCREPANCIES

### Overall Ratio

<table>
<thead>
<tr>
<th>Sum mandibular &quot;12&quot; mm.</th>
<th>Mean 91.3 = 0.26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum maxillary &quot;12&quot; mm.</td>
<td>Overall Ratio S. D. (o) 1.91</td>
</tr>
</tbody>
</table>

Range 87.5 - 94.8

### PATIENT ANALYSIS

If the overall ratio exceeds 91.3, the discrepancy is in excessive mandibular arch length. In above chart, locate the patient's maxillary "12" measurement and opposite it is the correct mandibular measurement. The difference between the actual and correct mandibular measurement is the amount of excessive mandibular arch length.

If the overall ratio is less than 91.3:

- actual mand. "12" = correct mand. "12" = excess mand. "12"

### Anterior Ratio

<table>
<thead>
<tr>
<th>Sum mandibular &quot;6&quot; mm.</th>
<th>Mean 77.2 = 0.22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum maxillary &quot;6&quot; mm.</td>
<td>S. D. (o) 1.65</td>
</tr>
</tbody>
</table>

### PATIENT ANALYSIS

If anterior ratio exceeds 77.2:

- actual mand. "6" = correct mand. "6" = excess mand. "6"

If anterior ratio is less than 77.2:

- actual max. "6" = correct max. "6" = excess max. "6"
APPROVAL SHEET

The thesis submitted by Carl George Gangitano has been read and approved by three members of the faculty of the graduate school.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

5/16/74
Date

Signature of Advisor