

**MORPHOLOGICAL VARIATION IN THE VERTEBRAL COLUMN
OF INDIGENOUS PEOPLES OF THE ARCTIC
AND AMERICAN NORTHWEST**

by

Lynda S. Wood

**A thesis submitted to the Department of Anatomy and Cell Biology
in conformity with the requirements for
the degree of Doctor of Philosophy**

**Queen's University
Kingston, Ontario, Canada
April, 1997**

© Lynda S. Wood, 1997



National Library
of Canada

Acquisitions and
Bibliographic Services

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale
du Canada

Acquisitions et
services bibliographiques

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced with the author's permission.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-20596-7

ABSTRACT

The inconsistent performance of non-metric traits in deciphering prehistoric population affinities has been blamed on (1) use of inappropriate traits, and lack of precision and reliability in scoring of traits, (2) effects of age, sex and inter-trait correlation on trait expression, (3) use of inappropriate distance statistic. Each of these requires further attention and are addressed in the present study. Fourteen traits of the sternum and vertebral column were described, the levels of intra- and inter-observer replicability in their scoring analyzed statistically, and their frequencies tabulated by age (young versus older adults), sex and population, in a large sample (n=1690) of U.S. Whites, U.S. Blacks and Native North Americans. Logit analysis was used to describe the effects of the variables population, age and sex on trait expression. Patterns of inter-trait association were analyzed using the phi coefficient. A novel distance statistic analogous to Mahalanobis D^2 and based on logit values derived from the modeling procedure was demonstrated, and the results compared to those derived from the Mean Measure of Divergence statistic (MMD). The pattern of population affinities revealed by the logit-based D^2 were examined for evidence pertaining to ethnogenesis in North America and in terms of the potential of these traits for forensic application.

Of the 14 logit models 11 contained the population term, supporting the assumption of a genetic basis for trait expression. Four also contained the age term; of these, two contained the population*age interaction term. The remaining three contained the sex term in addition to the population term; of these, one contained the population*sex interaction term. The observed pattern of inter-trait associations was explained better in

terms of the cranial/caudal border shift classification than the hypo/hyperostotic classification.

Spearman's rank-order coefficient showed highly significant correlation between the MMDs and logit-based D^2 values indicating the validity of the MMD. The MMD has the advantages of making optimal use of fragmentary samples and being easier to compute.

The Mahalanobis D^2 distances contradicted the Greenberg (1986) three-wave hypothesis of peopling of the New World. In agreement with Ossenberg's (1992, 1994) findings based on cranial traits, Aleuts and Eskimos are both more closely related to Amerindians than either group is to each other. Trait frequencies of U.S. Blacks are almost always closer to those of U.S. Whites than to those of Native Americans indicating that non-metric vertebral variants should be useful in North American forensic investigations.

ACKNOWLEDGEMENTS

I would like to take this opportunity to extend my thanks to those who have assisted me with this project.

I thank my supervisor, Dr. Nancy Ossenberg, who has worked tirelessly to ensure completion of this project. Her guidance and insight have contributed at all stages of the work. I thank her also for her on-going encouragement and understanding, both academically and otherwise.

Dr. Smith, director of Statlab and professor in the Department of Mathematics and Statistics at Queen's University, played an integral part of this project. I thank him for sharing his expertise and knowledge and for continuously being available for consultation, despite his already demanding schedule. This project would not have been possible without his involvement.

I thank various individuals who facilitated access to skeletal material and in particular Dave Hunt, Smithsonian Institution; Jerry Cybulski and Rachel Perkins, Canadian Museum of Civilization; Neils Lynnerup and Pia Bennike, Panum Institute, University of Copenhagen.

For their much appreciated administrative assistance, I thank Marilyn McAuley, Brenda McPhail, Anita Lister, and Anne Tobin all of whom form an integral part of the Department of Anatomy.

TABLE OF CONTENTS

ABSTRACT	i
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	v
LIST OF FIGURES AND ILLUSTRATIONS.....	vi
CHAPTER I: INTRODUCTION.....	1
<i>Historical Background</i>	1
<i>Genetic Studies on the Mouse</i>	2
<i>Anthropological Studies</i>	7
<i>Methodological Issues</i>	11
<i>Effects of Inter-trait Correlation, Age and Gender</i>	16
<i>Statement of the Problem</i>	26
<i>Statement of Objectives</i>	28
CHAPTER II: SAMPLES, TRAITS AND SCORING PROTOCOL.....	30
<i>Choice and Organization of Samples</i>	30
<i>Samples</i>	32
<i>Data Collection and Preparation</i>	41
<i>Observer Replicability</i>	47
<i>Trait Description</i>	55
CHAPTER III: STATISTICAL METHODS.....	90
<i>Descriptive Statistics</i>	90
<i>Logit Modeling</i>	90
<i>Building the Logit Model</i>	102
<i>Model Diagnosis</i>	104
<i>Inter-Trait Association</i>	106
<i>Distance Analysis</i>	108
CHAPTER IV: RESULTS	115
<i>Descriptive Statistics</i>	115
<i>Logit Modeling</i>	115
<i>Odds Ratios</i>	126
<i>Inter-Trait Association</i>	134
<i>Assessment of the Fit of the Logit Models, By Trait</i>	134
<i>Distance Analysis</i>	148
CHAPTER V: DISCUSSION.....	156
<i>Biological Interpretation of Logit Models</i>	156
<i>Inter-trait Association</i>	189
<i>Distance Analysis</i>	196
CHAPTER VI: SUMMARY AND CONCLUSIONS	208
REFERENCES.....	213
APPENDICES	224
CURRICULUM VITAE.....	241

LIST OF TABLES

1: Skeletal aggregates and samples by age and sex, and listed geographically from North to South.....	31
1a: Samples included in the Arctic/Inupiaq Eskimo aggregate shown in Table 1...	33
1b: Samples included in the South Alaskan Eskimo aggregate shown in Table 1...	33
1c: Samples included in the Aleut aggregate shown in Table 1.....	34
1d: Samples included in the Plains Indian aggregate shown in Table 1.....	34
2: Skeletal aggregates, samples, provenience and institution where the material was studied.....	35
3: Skeletal aggregates, samples and data recorders.....	42
4: Phi and corrected phi coefficients for inter-observer agreement analysis.....	50
5: Phi and corrected phi coefficients for intra-observer agreement analysis.....	51
6: Percentage frequency and total number of observations per trait, by population group, age and sex.....	116
7: Logit model and associated probability values for 14 non-metric traits of the vertebral column based on the dataset of six population groups	119
8: Contribution of the population group term as measured by its associated G^2 , degrees of freedom and probability value.....	121
9: Contribution of the age term as measured by it associated G^2 , degrees of freedom and probability value.....	124
10: Contribution of the sex term as measured by it associated G^2 , degrees of freedom and probability value.....	124
11: Contribution of the interaction terms as measured by their associated G^2 , degrees of freedom and probability value.....	125
12: Odds ratios and associated confidence intervals, X^2 and probability values per trait, by logit model parameters.....	127
13: Inter-trait association matrix with phi coefficients above the main diagonal and probability value under a null hypothesis of zero association below the main diagonal.....	135
14: Adjusted residuals for each trait by population group, age and sex.....	138
15: Logit model and associated probability values for 13 non-metric traits of the vertebral column based on the dataset of 12 population groups to be used in the distance analysis	149
16: Distance matrix with Mahalanobis distances above the main diagonal and MMD distances below the main diagonal.....	152
17: Distance matrix with MMD distances below the main diagonal and their associated standard deviations above the main diagonal.....	154
18: Breakdown of phi values by non-classified versus classified cranial/caudal border shift traits.....	195
19: Mean percentage frequency for 14 traits, by three major "racial" groups.....	206

LIST OF FIGURES AND ILLUSTRATIONS

1: Anterior view of sternum showing sternal aperture.....	56
2: Superior view of first cervical vertebra showing atlas bridge posterior.....	63
3: Posterior view of first cervical vertebra showing atlas bridge lateral.....	63
4: Superior view of first cervical vertebra showing atlas transverse foramen defective.....	66
5: Lateral view of second cervical vertebra showing axis transverse foramen defective.....	66
6: Superior view of sixth cervical vertebra showing double transverse foramen...	70
7: Superior view of seventh cervical vertebra showing costal foramen.....	70
8a: Superior view of seventh cervical vertebra showing articular facet for cervical rib.....	73
8b: Lateral view of seventh cervical vertebra showing articular facet for cervical rib.....	73
9: Lateral view of first lumbar vertebra showing articular facet for lumbar rib.....	76
10a: Anterior view of sacrum showing S ₁ lumbarization.....	80
10b: Posterior view of same sacrum showing S ₁ lumbarization	80
11a: Anterior view of sacrum showing S ₁ lumbarization.....	80
11b: Posterior view of same sacrum showing S ₁ lumbarization	80
12: Posterior view of sacrum showing S ₁ cleft neural arch.....	85
13: Dendrogram for Mahalanobis distances based on 10 non-metric traits of the vertebral column.....	197
14: Dendrogram for MMD distances based on 10 non-metric traits of the vertebral column.....	198
15: MDS scatterplot for Mahalanobis distances based on 10 non-metric traits of the vertebral column	200
16: MDS scatterplot for MMD distances based on 10 non-metric traits of the vertebral column.....	201

CHAPTER I: INTRODUCTION

Historical Background

Non-metric (discrete) traits of the skeleton are discontinuous morphological variants that are characterized as present or absent. Though they are known to occur throughout the skeleton, to date, those observed in the cranium have been the main focus of research.

Various non-metric traits were first noted by early anatomists, but not until the beginning of the nineteenth century did researchers seek biological explanations for their appearance. The theme common to most theories was that of primitiveness or atavism, representing reversion to an ancestral condition or remnants of a previous evolutionary stage. The presence of a trait was argued to prove racial inferiority or primitiveness, e.g., in Blacks (Saunders, 1989).

By the beginning of the twentieth century the research focus began to change with the appearance of major works that were largely descriptive. The most notable were those of Le Double, who in 1903 published the first in a series of monographs devoted entirely to non-metric traits. Le Double's works are based on observation of innumerable dissecting-room cadavers. Especially relevant to this thesis is his *Traite Des Variations Des Os De La Colonne Vertebrale* (1912) which was the first major work on non-metric traits of the vertebral column; it stands today as an important classic. Each trait is meticulously described, along with information on soft tissue relationships. In addition, Le Double describes the trait as it appears in human fetal specimens and in various other species.

Within the context of anthropological studies Russell (1900) demonstrates, with a large series of Amerind skeletal samples (approximately 2000 individuals), that several cranial traits vary in frequency among regional populations. In his group of publications entitled *The Non-metrical Morphological Characters of the Skull as Criteria for Racial Diagnosis*, Wood-Jones (1930-1931 and 1933-1934) describes and reports frequencies of 26 cranial traits observed in samples of Chinese, Hawaiian and Guam skeletons. He states that the traits “are of utmost importance in diagnosing the characters of individuals belonging to minor groups”.

Genetic Studies on the Mouse

Quasi-continuous model

In the 1950's a series of articles began to appear under the heading *Genetical Studies on the Skeleton of the Mouse*. The basis of these articles was the realization that a number of non-metric traits observed on the mouse skeleton were confined to, or varied in, frequency among inbred strains. Extensive cross-breeding experiments between two pure inbred mouse strains led Gruneberg (1952) to propose the “quasi-continuous” model of inheritance as a means of explaining the genetic basis of the traits. Absence of the third molar serves as a clear example: Underlying the discontinuous phenotypic expression of third molar as either present or absent in the mature mouse, is a continuous variable in the fetal mouse, called *trait liability*, in this case size of the tooth rudiment, controlled by multiple genes with additive effects. As the fetus develops, the tooth rudiment increases in size as a continuous variable. However, superimposed on this underlying continuous

variable is a developmental *threshold*: if, at a critical stage of development the rudiment has not yet attained a sufficient size, the rudiment is simply resorbed by the surrounding tissue.

In the third molar example the threshold is one of size but this is not necessarily the case for all traits; for most traits the physiological factors determining the threshold are unknown. Nor is the threshold for all features reached prenatally; for certain ones the critical developmental stage may occur at puberty or even later.

A quasi-continuous variant can be recognized by a combination of the following characteristics (summarized from Gruneberg, 1952:108):

- 1) Both the normal and abnormal states can be expressed at various stable levels; i.e. a trait can be graded.
- 2) If a trait is capable of graded expression, populations with a higher frequency of trait expression should also contain a higher proportion of severely affected individuals among all affected ones.
- 3) The trait is sensitive to environmental influences (both pre and post-natal).
- 4) The trait is sensitive to genetic influences such as sex.
- 5) The effects of the multiple genes are additive and may be modifiers of major genes.

Gruneberg stresses that the phenotypic expression of the trait is the remote effect of gene action and interaction combined with environmental influences.

Environmental influences

Subsequent research attempted to assess the influence of environmental factors on trait expression. Searle (1954a) studied variation in trait expression of 20 non-metric traits observed in two strains of inbred mice. Genetic factors influencing trait expression included sex and the inherited difference in trait expression between and within each strain. Non-genetic factors include: those acting on whole sibships due to long-lasting maternal influence; those acting on whole litters due to common intra-uterine environment (maternal age, parity, litter size, length of gestation); those acting on individuals; those acting independently on the left and right side of individuals. Searle found that undetected non-genetic factors accounted for 80% of the variance in three quarters of the characters studied. He also found that there was a tendency for early litters/young mothers to have the highest number of abnormalities; and that some traits were influenced by maternal age. When sex differences were discovered they did not appear to be associated with size.

Maternal effects

In a later paper Searle (1954b) focused his research on the influence of maternal effects on trait expression observed in a single inbred strain of mouse. During pregnancy one group of mothers was fed drinking water containing thiouracil (which depresses thyroid activity and thus slows growth and metabolism). Another group was fed a diet of oats (which is deficient in protein) and the final group was fed a diet slightly less nutritious than the standard diet. Each of these "treatments" has the potential of affecting maternal physiology and thus altering the intra-uterine environment. Thiouracil had a slight effect on the trait frequency but it is possible that the post-natal environment (i.e. during

lactation) was an influencing factor. The oats diet had a significant effect on trait frequency with nine of the twelve traits either increasing or decreasing in frequency. Again, the post-natal and pre-natal environment are probably both responsible. Trait frequencies in the offspring of mothers fed the slightly deficient diet were not significantly altered. In terms of individual traits, all sublimes of the inbred strain did not always react the same way in response to a change in diet; e.g., for one trait the frequency increased from 0 to 16% in one subline, but remained constant in another subline.

As a follow-up to Searle's (1954b) research Deol and Truslove (1957) set out to determine:

- 1) if Searle's results from the oat diet experiments were repeatable,**
- 2) if other unbalanced diets, in addition to the oats diet, would have similar effects on the skeleton,**
- 3) the physiological channels through which maternal diet affects skeletal differentiation of offspring.**

The authors were also interested in the overall effect the various diets had on the growth of the mice (measured through birth weight and weight at 21 days). For nineteen of the twenty-two traits the results of Deol and Truslove's experiments were in agreement with Searle's oat diet experiment. Each of the four diets, oats, wheat, buckwheat and barley, had a similar effect on the skeleton but the least deleterious diet (as measured by birth weight and weight at 21 days) affected the skeleton the most, while the most

deleterious diet affected the skeleton the least. In at least ten of the traits an underlying reduction in skeletal size was responsible for the changes in trait expression.

Howe and Parsons (1967) examined the effects on the overall pattern of trait frequencies of the following factors: parity, maternal age, litter size, age at death, lactation status of mother while carrying offspring, and pregnancy status of the mother while lactating. They found that in most cases *size* of the offspring (body weight at 60 days) was correlated with these factors, and that their effect on trait frequencies was mediated by size; e.g., if litter size was large the offspring weight would be small and the pattern of trait frequencies different from that of controls. These results are in direct contrast to Deol and Truslove's (1957) research in which those mice most affected by dietary change (as measured by birth weight and weight at 21 days), were least affected in terms of skeletal changes.

Wild mouse studies

Berry (1963) subsequently showed that frequencies of non-metric skeletal traits varied between wild mouse populations. He examined the frequency of 35 traits in a series of wild mice captured from 15 different ricks. Mice colonize a rick at the end of the summer and multiply rapidly until the spring when the ricks are threshed. Research indicates that by spring time, most mice living in a single rick are relatives (Berry, 1963).

Berry was also interested in how dietary differences would affect trait frequencies. Of the 15 ricks two were composed of oats, five of barley, and eight of wheat. In the initial statistical analysis diet is determined to have only a small effect on trait frequency with the

main source of variability occurring among ricks, regardless of the composition of the rick. While this may be true, it should be noted that unlike the controlled dietary experiments conducted on the inbred mouse strains, the wild mice were not restricted in quantity or variability of food intake. Those living in the barley ricks could have exploited other food resources in the general area.

More important was Berry's demonstration of a method for using the combined frequencies of all traits in order to obtain a measure of distinctiveness or divergence among the 15 rick populations. The method was devised by Smith and first used by Grewal (1962) to measure the rate of genetic divergence in sublines of an inbred strain of mouse. Though the measures of divergence between ricks were not startling the author states:

the results obtained show clearly that, in conditions of nature, the epigenetic skeletal patterns of different populations can be used to characterize those populations genetically (Berry, 1963:218).

Anthropological Studies

The methodology of Berry's (1963) wild mouse study was adopted for the study of human skeletal material curated in British museums (Berry and Berry, 1967). The authors' objective was to determine the availability and extent of non-metric trait variation in the human skeleton and to test whether Smith's Mean Measure of Divergence (MMD) could be used to determine relative biological distances among human populations. Several anthropologists had already used non-metric traits, with some success, to study human population affinities (Laughlin and Jørgenson , 1956; Brothwell, 1959 in Saunders,

1978) but Berry and Berry (1967) were the first to use a large battery of traits in combination with Smith's Mean Measure of Divergence statistic. They argued that the traits result from "normal developmental processes and are genetically determined" (p. 361), and because they are analogous to many observed on the mouse skeleton, share a similar quasi-continuous mode of inheritance. The authors studied 30 cranial traits in 585 adult crania originating from eight geographical regions. Their results are inconclusive but hint at the potential of non-metric traits as a tool for the study of prehistoric population affinities. In addition, the authors claim non-metric traits to be superior to metric traits because of their lack of age and sex effects, nonexistent inter-trait correlation, and high inter/intra-observer agreement. All of these can potentially affect the distance statistic. They also state that the data could be collected with relative ease, and that fragmentary material could be easily analyzed.

It seemed that these claims were too good to be true. Berry and Berry's (1967) publication was followed by an uncritical and enthusiastic acceptance of the technique. Expectations remained high for several years. Despite the inaccuracy and subsequent criticism of their claims, Berry and Berry must be given due credit for their role in instigating research on the use of non-metric traits to study prehistoric population affinities, much of which has refined the technique and strengthened the results.

Berry and Berry's (1967) publication initially resulted in a number of studies of non-metric variation as a means of elucidating migration patterns and genetic relationships among prehistoric populations. Many took the form of graduate theses. One of the first works was published by Berry, Berry and Ucko (1967) and was an attempt to measure

genetic change in ancient Egypt by using non-metric traits of the skull to differentiate among various skeletal samples. The objective of the research was to clarify ancient Egyptian history, not test the concordance of the non-metric trait data with other sources of information. This theme generally continued with further work: Non-metric data were used to elucidate affinities among prehistoric peoples, not test the specific assumptions and precision of the technique (Birkby, 1973; Finnegan, 1972; Kellock and Parsons, 1970a & 1970b; McWilliams, 1974). Several researchers focused on relationships within well-defined populations, e.g., Jantz (1970) on the Arikara, McWilliams (1974) on the skeletal material from the Gran Quivira Pueblo and Birkby (1973) on four spatially close and culturally similar sites in Arizona. Others analyzed samples from broad geographical regions, e.g., Kellock and Parsons (1970a) on Australian Aborigines and, subsequently (1970b) on the relationship of prehistoric Australian Aborigines to prehistoric Melanesians and Polynesians.

Though infracranial non-metric traits were known to exist from the work on mice and as the result of anthropological research (Anderson, 1968), cranial traits were used almost exclusively, the source being Berry and Berry's (1967) original list of 30 traits. In addition, Smith's Mean Measure of Divergence was the statistic of choice for calculating relative biological relatedness between samples. In some cases results on the non-metric analysis were compared to archaeological and/or linguistic data if available (Finnegan, 1972) or craniometric data (Buikstra, 1972; Jantz, 1970).

Berry and Berry's (1967) assumptions of lack of age and sex effects and nonexistent inter-trait correlation were not universally accepted as truths. Several researchers tested

age effects (Birkby, 1973; Buikstra, 1972; Corruccini, 1974; Suchey, 1975) and sex effects on trait frequency (Birkby, 1973; Corruccini, 1974; Finnegan, 1972; Jantz, 1970; Suchey, 1975). They also tested for significant inter-trait correlation (Buikstra, 1972; Corruccini, 1974; Kellock and Parsons, 1970a; McWilliams, 1974; Suchey, 1975). Results were inconclusive and seemed to vary by skeletal sample and statistical methodology.

By the mid 1970s there continued to be a lack of consensus as to the utility of non-metric trait analysis as a method of studying prehistoric population affinities. Some researchers concluded that non-metric traits were only useful in conjunction with, or as confirmation of, other distance measures (Corruccini, 1974; Zegura, 1975). Others concluded that non-metric trait frequency patterns do reflect, and are concordant with, archaeological and linguistic data (Finnegan, 1972; Ossenberg, 1977). Fortunately, the ambiguous results spurred a shift in focus from prehistoric population affinities to methodological issues. It was becoming apparent that the results of a population study were largely dependent on the methods used.

Corruccini's (1974) work marks the beginning of this shift in focus. He made a substantial contribution to non-metric trait research when he examined the effects of age, sex, and inter-trait correlation on a sample of individuals of known age and sex. This approach was taken because, as the author argues, investigation of age and sex effects and inter-trait correlation had been conducted, until this time, with archaeological samples. By their very nature, archaeological samples suffer from uncertain age and sex assignment, and suffer from differential preservation. In addition to the problem of age, sex and inter-

trait correlation effects, methodological issues have plagued non-metric trait research; e.g., choice of distance statistic and appropriate scoring of bilaterally expressed traits. The following sections present a brief review of the literature pertaining to these issues.

Methodological Issues

Distance statistic

Smith's Mean Measure of Divergence (introduced in Grewal, 1962) is the most widely used statistic for non-metric trait distance analysis. Sjøvold (1977), in his doctoral dissertation on the Mean Measure of Divergence (using variants in the skeleton of the red fox), demonstrates the properties and theoretical soundness of this distance measure. The MMD represents the *average* difference between two skeletal samples with respect to a number of traits. The frequency of each trait, by skeletal sample, is first transformed into an angular value, Theta (θ). The angular transformation stabilizes the variance of the sample frequency, which otherwise can vary significantly depending on an unknown parameter: frequency of the trait at the population level. If trait frequencies among skeletal samples have widely disparate variances, those with smaller variances will be more heavily weighted in the distance calculation. Green and Suchey (1976) show that, for small sample sizes, the Freeman-Tukey transformation is more appropriate than that developed by Smith (Grewal, 1962).

Smith's Mean Measure of Divergence is defined as follows:

$$\text{MMD} = \frac{\sum_{i=1}^Z (\theta_1^i - \theta_2^i)^2 - \left(\frac{1}{T_1^i} + \frac{1}{T_2^i} \right)}{Z}$$

θ_1^i = the transformed frequency of the i th trait in the first skeletal sample

θ_2^i = the transformed frequency of the i th trait in the second skeletal sample

Z = total number of traits used in the analysis

T_1^i = total number of observations in the first skeletal sample for the i th trait

T_2^i = total number of observations in the second skeletal sample for the i th trait

The quantity $\left(\frac{1}{T_1^i} + \frac{1}{T_2^i} \right)$ represents a sample size factor correcting for the combined variance due to random sample fluctuation. It makes the variances a function of the samples sizes, rather than a function of the trait frequencies (Konigsberg, 1987:157). The correction factor is subtracted from the Theta-squared difference in order to increase accuracy of the results. When the Freeman-Tukey transformation is used the calculation of the correction factor is slightly different. Finnegan and Coopriider (1978) provide a comprehensive review of the various distance equations. To summarize, they applied various transformations and distance equations to a set of data in order to determine if calculations varied significantly between formulae. The results indicate that there is a high degree of similarity among all equations when the number of skeletal samples, sample sizes, and the total number of traits used, are large.

Recently, Smith's Mean Measure of Divergence has been criticized on two grounds: Firstly, the MMD does not take inter-trait correlations into account. This has added impetus to one of the on-going and seemingly unresolvable debates about non-metric skeletal variants: Are there significant correlations between traits? When measurement

(continuous) variables are employed in population studies, inter-trait correlation is acknowledged and accounted for, e.g., the Mahalanobis distance formula takes into account inter-trait correlation by way of the pooled dispersion matrix (Constandse-Westermann, 1972).

The second criticism is conceptually based. The MMD cannot accommodate the fact that the traits, though appearing to be categorical, have a continuous underlying distribution of liability (Blangero and Williams-Blangero, 1991; 1993). Their phenotypic expression is the threshold or liability level and can be considered as a measurable value of the continuous distribution. If this threshold could be measured for each trait, threshold means could be used in a distance measure analogous to Mahalanobis D^2 , which would eliminate the conceptual and statistical weaknesses perceived to be inherent in the MMD.

Bilateral traits and asymmetry

There is disagreement over how to calculate the frequency of a bilaterally occurring trait. The following three methods are most commonly used:

- 1) scoring by side in which the frequency is computed as number of sides with trait present divided by total number of sides observed,
- 2) scoring by individuals in which frequency is computed as number of individuals with trait present on one or both sides divided by number of individuals observed,
- 3) scoring by individual side in which frequency is computed as number of individuals with trait present on just the left *or* just the right side divided by number of individuals observed.

The method chosen can substantially alter trait frequencies. As an example, consider a sample of 100 perfectly preserved crania, 50 of which have the trait present on the left side while the other 50 have it present on the right side. Methods one and three give trait frequency of 50% while method two gives trait frequency of 100%. Alternatively, if 25 of each of the 50 skulls with trait present on the left expressed the trait bilaterally (i.e. 25 skulls have trait present simultaneously on both left and right side) methods one and three give trait frequency of 50% while method two would produce trait frequency of 75%. Moreover, methods two and three would underestimate trait frequency in poorly preserved skeletal samples while method one would introduce redundant information into statistical calculations.

Researchers who have tested for side interdependence of bilateral traits have found high, but not perfect, dependence exists (Birkby, 1973; Buikstra, 1972; Finnegan, 1978; Molto, 1983; Saunders, 1978). In addition, researchers have found that the ratio of bilateral to unilateral trait presence increases with age (Korey, 1970; Saunders, 1978) and thus may simply reflect an age factor. Asymmetry has been assumed to be random and result from developmental noise but Trinkaus (1978) found that in over half of the traits that he tested the unilateral versus bilateral frequency differences were greater than 10%, indicating to him that asymmetry was more than just a “random” phenomenon. If asymmetry were truly random, method three for calculating trait frequencies would be the most accurate. However, there is evidence that the unilateral expression of certain traits is directional (Molto, 1983; Saunders, 1978) and may be related to richer nerve and blood supply on the right side of the body (Ossenberg, 1969; Ossenberg, 1981; Searle, 1954a).

Ossenberg (1981) argues that bilateral trait expression represents higher genetic liability for the trait and thus more weight should be assigned to bilateral than to unilateral expression. In support of this argument the author finds that as the frequency of mylohyoid bridge and third molar agenesis increases the frequency of bilateral to unilateral expression increases as well. This may be related to one of the characteristics used to identify a quasi-continuous trait as proposed by Gruneberg (1952); i.e. regression of trait expression on incidence. Specifically, populations with higher trait frequencies will also have a higher number of individuals with more severe trait expression.

An alternative view to Ossenberg's (1981) is that held by Korey (1980). He examined one trait, supraorbital foramen, to determine whether expression of a trait on the left and right side of an individual are genetically correlated. Because the frequency of bilateral to unilateral trait expression increases with developmental age, Korey states that unilateral versus bilateral expression has minimal genetic significance and that scoring trait frequencies by sides would result in redundant genetic information. McGrath and colleagues (1984) calculated "genetic correlation between sides" and "heritability of asymmetry" for 13 traits in a series of 442 rhesus macaques, 133 of which were mother-offspring pairs. They found a significant level of genetic correlation between sides and low to nonsignificant values of heritability of asymmetry. The former supports Korey's (1980) argument that sides contain redundant genetic information and the latter refutes Ossenberg's (1981) argument that unilateral versus bilateral trait expression is genetically influenced. McGrath and colleagues (1984) do caution against generalizing their results

from monkey to human because genetic correlations and heritability estimates are population and species specific.

It should be noted that Green, Suchey and Gokhale (1979) propose an adjustment of Smith's MMD to correct for redundant genetic information and the inflated sample size that results when the side method (method one) is used. Molto (1983) argues that in addition to being time consuming to calculate, the overall effectiveness of the adjustment factor is almost negligible. Today, the availability of high speed computers eliminates the time constraint problem.

Konigsberg (1987:102-107) provides an excellent discussion on the appropriate methods for scoring bilateral traits. If one is interested in the individual as the unit of study (and not the side) he proposes that scoring by side (method 3 above) is most appropriate. The use of this method does not require perfectly preserved skeletal material as has previously been assumed. Konigsberg (1987:105) explains "both sides can be scored when possible, and if the states of the two sides disagree, then one side can be randomly selected to represent the individual". If the assumption that asymmetry is random is correct, unilateral trait expression on either the left or right side should be approximately equal, except for sampling error.

Effects of Inter-trait Correlation, Age and Gender

Inter-trait correlation

One of the major assumptions that must be met in using Smith's Mean Measure of Divergence is that traits used in the analysis are not correlated. As summarized by

Saunders (1978) there are three main reasons for two traits occurring together in the same individual with a higher frequency than would be expected by chance:

- 1) Traits represent expressions of the same underlying variable, e.g., the association of double transverse foramen on contiguous cervical vertebrae.**
- 2) Traits are associated through a generalized or localized developmental phenomenon such as retarded or arrested growth (hypostotic) or excess bony development (hyperostosis), e.g., a general hyperostotic factor could underly a joint occurrence of atlas lateral bridge and double transverse foramen of the sixth cervical vertebra.**
- 3) The traits share a common regional, embryological or genetic origin, e.g., those representing caudal or cranial border shifts in axial segmentation.**

Truslove (1961) tested 31 non-metric traits observed in two inbred strains of mice for inter-trait correlation and found that fewer correlations occurred than were expected by chance. By comparing the pattern of correlation between the two strains, she found 11 trait-pair correlations that were common to both and proposes that these may be biologically meaningful. However, because none of the correlations exceed 0.3, Truslove concludes that inter-trait correlation is not strong enough to distort population distance measures.

Berry and Berry (1967), aware of the possibility that some non-metric traits of the human cranium may be correlated, conducted pair-wise correlation tests for 30 variants in a sample of 99 Egyptian skeletons. Ten traits were found to be correlated. Though only four would be expected by chance, the authors conclude that there is “extremely little inter-correlation” (1967:373). This conclusion seems unwarranted, and in any case, it is

doubtful that a sample of 99 is large enough to detect significant association for any but the most common variants; i.e. those occurring in a frequency larger than 25%.

Hertzog (1968) examined correlation between seven cranial non-metric traits in a total of 366 crania, from six geographically defined groups (Polynesian, African, Amerindian, Asiatic, European, and Indian), and found a large number that were significant. When Benfer (1970) re-evaluated Hertzog's data he noted that five of the seven traits were accessory sutural ossicles for which inter-trait associations are naturally expected. He also noted, that in spite of the statistical significance of the correlations, the actual amount of shared variation was very small and would not affect the outcome of the distance analysis.

Other researchers have used the X^2 statistic to test for trait independence and have found fewer statistically significant associations than would be expected by chance (Kellock and Parson, 1970a; Saunders, 1978; Suchey, 1975). Nonetheless, as Molto (1983) notes, both Kellock and Parsons (1970a) and Suchey (1975) followed Berry and Berry's (1967) example of testing for inter-trait correlations in a small portion of, or a single sample derived from the total sample intended for distance analysis, and this may be inappropriate since the patterns of inter-trait correlation are not necessarily consistent among populations.

In his analysis of American White and Black dissecting-room samples, Corruccini (1974) used X^2 to test for inter-trait correlation, and also measured the relative level of association between traits, using Yule's Q coefficient. He found, that though correlations were not high, they were significantly greater than zero. In addition, he used Spearman's rank-order coefficient to test for correlation between traits that were scored on a graded

scale, and found the level of statistical significance increased. Because Spearman's rank-order correlation test is a more powerful statistic than the chi-squared test, Corruccini suggests that it more accurately reflects the underlying biological reality: significant correlations do exist between traits.

Molto (1983) notes that the phi coefficient, used for categorical data, is the mathematical equivalent of the Pearson product-moment correlation coefficient and is as powerful. In a large aggregate of 17 Iroquois skeletal samples, he found 20 significant values of phi, though only four would be expected by chance.

Sjøvold (1977:77) showed that "with increasing sample size the fact that many traits are genetically and probably also environmentally correlated may be gradually discovered". He argues that most prehistoric skeletal samples subject to distance analysis are smaller than the sample he studied, and that if correlations between traits are not detected or are minimal, they will not affect the distance measures.

It should be noted that not all researchers share Sjøvold's view. Buikstra (1972) removed traits that were significantly associated with one or more other traits in her analysis of Illinois archaeological remains and Molto (1983) did the same with a number of traits he studied in an Iroquois archaeological sample. In her work on Native American ethnogenesis, Ossenberg (1976, 1977, 1992, 1994) amalgamated inter-correlated sutural bones of three sites on the cranial vault into a single trait (wormian bones), in order to reduce redundancy, and Saunders (1978) followed a similar procedure with some of the infracranial traits she studied.

Age regression

Another major assumption that must be met in order to use Smith's Mean Measure of Divergence with skeletal samples including individuals of all ages at time of death, is that the traits are not age regressive. Ossenberg (1969) was the first to conduct a detailed investigation on the effects of age on non-metric trait frequencies. Her analysis, based on archaeologically-retrieved skeletal samples mainly representing the Arctic and Plains regions of North America, included both sub-adult and adult cranial material. In summary, Ossenberg found that hypostotic traits (those representing reduced bone growth) tend to decrease with increasing age, while hyperostotic traits (those representing excess bone growth) tend to increase with increasing age. In addition, the author found some traits that were not affected by age and others that appeared to exhibit an age-sex interaction. These apparent differences were not tested statistically.

When Berry and Berry (1967) published their major work on non-metric traits of the human cranium they stated that all traits were age stable. Later researchers (Finnegan, 1972; Kellock and Parsons, 1970a and 1970b), trusting Berry and Berry's (1967) claim, did not examine their skeletal samples for age influenced traits before proceeding with the distance analysis. It is now generally accepted that changes in non-metric trait expression do occur during skeletal growth (Corruccini, 1974; Korey, 1970; Ossenberg, 1969) and Saunders (1978) points out that for several traits, a feature occurring universally in the juvenile skeleton as a normal developmental stage, must be retained in the adult in order for the trait to be scored as "present". The obvious solution to the problem of age influence is to exclude subadult material from the distance analysis, or follow Ossenberg's

(1976) and Molto's (1983) example and include subadult material only for the traits that prove to be age stable. It should be noted that age effects are not necessarily consistent among populations (Ossenberg, 1976), thus requiring that each skeletal sample be tested separately.

Buikstra (1972) solved the age effects problem by using only post-adolescent material (categorized as all individuals over 12 years of age) and scoring all partial manifestations of a trait (i.e. bony spurs rather than a complete bridge) as present. With these adjustments she found that only two of 27 traits had a statistically significant age effect when subjected to the Students t-test. Two points are in order here: the appropriateness of the statistical test is questionable and, as Saunders (1978) notes, many partial trait manifestations are not simply developmental stages, but instead persist through to, and throughout adulthood.

Corruccini (1974) notes that age assignment of archaeological material is often inaccurate, particularly in older age groups. In order to test the assumption that non-metric traits are not affected by age, he used a dissecting-room sample of known age, sex and race. The chi-square and MMD statistic were employed to detect differences in trait frequency between young adults (19-39) and old adults (40 and over), by sex, and racial group (Black and White). The results of the chi-square test indicate that twice the number of significant differences were found than would be expected by chance, while the results of the MMD test indicate that all comparisons were statistically significant. The author states "The multivariate divergence test indicates that cumulative age divergence over many traits is more important than marked divergence in a few" (1974:435). Berry (1975)

responded to Corruccini's (1974) claim by examining age variation in trait frequency in a different skeletal sample of known age and sex. She pooled males and females, used seven adult age groups, and computed the Student's t-test to compare mean age of those with the trait versus mean age of those without the trait. She discovered only one significant difference and thus concluded that trait frequency was not affected by age.

Suchey (1975), based on her study of California archaeological samples, acknowledges that some traits are affected by adult age changes but argues that if the demographic profiles of all the samples used in the analysis are similar, as they were shown to be in her study, age effects would be negligible.

The year 1978 marks the appearance of two of the first major analyses focused on infracranial non-metric traits. Employing archaeological samples representing Aleut-Eskimo, Arikara Indians and Late Woodland Indians, Saunders (1978) used two statistical tests to examine the differences between young (19-29) versus old (30 and over) adults, separated by sex, and geographical derivation. The chi-square test indicates that the percentage of statistically significant results, by subgroup, are always greater than would be expected by chance. The distance statistics separated subgroups first by geographical derivation, then by sex, and finally by age. Smith's Mean Measure of Divergence showed statistically significant differences between the two age groups within each geographical area. Saunders (1978:303) concludes that "adult age changes in infracranial trait frequencies are strong enough to affect a distance statistic"

Finnegan (1978) also examined adult age changes but he did so on a dissecting-room sample consisting of individuals of known age and sex. He separated specimens by sex,

racial group (Black and White), and age group (five age categories beginning with 20-29 and ending with 60-69), and checked for statistically significant correlations between trait and age group. Twenty of the 240 correlations were significant. When the chi-square test was used to determine if trait frequencies were significantly different between the youngest and oldest age, only 11 comparisons were found to be significant, one less than would be expected by chance. The author concludes that infracranial traits are only minimally affected by age, and the effect is not strong enough to alter the distance statistics. If the samples in the analysis are demographically similar with respect to age, then no correction is necessary for age dependent traits.

Gender differences

The use of Smith's Mean Measure of Divergence with pooled-sex samples is based on the assumption that the traits used in the analysis are not affected by sexual dimorphism. When Berry and Berry (1967) tested cranial non-metric traits for gender differences, they pooled all skeletal samples into a grand male and a grand female sample, and used the MMD statistic to detect significant differences. Obviously, if the differences between the sexes are not consistent across samples, the potential exists for a "cancelling" effect. Thus it is not surprising that the authors found no significant differences between the two groups.

Despite the illogical nature of this test, other researchers (e.g., Finnegan, 1972) have followed Berry and Berry's (1967) example and pooled males from all population samples, likewise females from all population samples, before testing for gender differences by trait. Jantz (1970) also followed this procedure, though it could be argued that he was justified

in pooling all his samples because they were all Arikara. Others have used the chi-square statistic to test for sex differences among samples, and having found fewer statistical differences than would be expected by chance, pooled males and females for subsequent analyses (Birkby, 1973).

When Ossenberg (1976) used the Mean Measure of Divergence statistic to compare trait frequencies between males and females in three large skeletal samples (Dakota Sioux, Eskimo, Aleut), fewer significant differences were detected than would be expected by chance. Though the author was justified in pooling the sexes in this case, she stresses that not doing so in any case could result in significant error in distance measurements, as a result of the small sample sizes that result from analyzing the males and females separately. Suchey (1975) agrees with this approach. In addition, Suchey eliminated some male crania from her distance analysis of California Amerinds in order that both sexes would be equally represented in each of the three skeletal samples she compared.

Other researchers have found a greater number of significant sex differences in trait frequency than would be expected by chance (Berry, 1975; Corruccini, 1974; Finnegan, 1978; Molto, 1983; Saunders, 1978). Berry (1975) used the chi-square statistic to test for sex differences in a skeletal sample of known sex, and compared the patterns observed with those reported in the literature. She found that the traits affected varied by sample. Berry (1975) hypothesized that sex differences may act in opposite directions in different samples, and provided that enough variants are used, cancel each other out.

Corruccini (1974) compared sex differences in a sample of Blacks and a sample of Whites of known sex, with both the chi-square statistic and Mean Measure of Divergence

statistic, and concluded from this study that non-metric trait distance analyses should be based on two samples, one composed of male individuals and one composed of female individuals.

Finnegan (1978) also used chi-square to test for significant sex effects but he did so with infracranial traits and used the same skeletal sample as Corruccini (1974). Though there were more significant differences than would be expected by chance, the author judges that infracranial non-metric traits fare slightly better than do cranial traits.

When sample sizes are too small to separate males and females prior to the distance analysis three options remain:

- 1) Eliminate gender dependent traits from distance analysis.
- 2) Use either males or females (but not both) in distance calculations for gender dependent traits.
- 3) Keep the proportion of sexes equal across skeletal samples.

It has been noted (Finnegan, 1978) that many of the sexually dimorphic features are also the most valuable for distinguishing between populations. Eliminating this information from the distance analysis could substantially reduce intra- and inter-population variability.

One might intuitively expect males to have a higher frequency of hyperostotic traits (excess bone growth) and females to have a higher frequency of hypostotic traits (reduced bone growth) as a result of sexual dimorphism in size. Those that have examined sex differences in this context (Molto, 1983; Ossenberg, 1969; Saunders, 1978) have found this to be the case for some, but not all, sex-dependent traits. Sjøvold (1977) investigated

the effects of size on the occurrence of sexually dimorphic non-metric traits in the fox skull and found that in 50% of the cases, body size was correlated with trait expression.

A final point should be emphasized with respect to apparent male-female trait frequency differences in an archaeological sample: because of cultural practices relating to marriage and residence patterns, or raiding neighboring tribes for female captives, in some cases apparent sex differences could, in fact, be population differences. Assuming that regardless of population origin, each gender in the sample was contributing to the gene pool of the next generation in that village or region, the only appropriate way to attempt to represent that gene pool is to amalgamate male and female skeletal samples no matter that marked trait frequency differences are observed. Except for those workers explicitly using different male-female distance measures to focus on residence pattern (Lane and Sublett, 1972; Spence, 1974) this important consideration appears to have been overlooked by workers fussing over how to ameliorate the effect of sex differences on their distance measures.

Statement of the Problem

Non-metric traits of the vertebral column certainly require more attention. Fewer than a half dozen anthropological studies, comparable to the present one, exist worldwide (Barnes, 1994; Finnegan, 1978; Gaherty, 1970; Merbs, 1983; Saunders, 1978; Winder, 1981). The power of vertebral variants to characterize major racial groups, hence their utility in forensic applications, should be assessed. Likewise, we need to explore their potential for addressing problems relating to the peopling of North America. Though many variants are known to exist in this part of the skeleton (Anderson, 1968; Le Double,

1912), they have been neglected, possibly as a result of the complexity of the vertebral column (Jackes, 1977), coupled with its generally poor preservation at burial sites and neglect during archaeological retrieval.

The effects of age, gender and inter-trait correlation are not well understood and need to be explored further using current analytical techniques based on logit modeling. It is not clear to what extent each of these variables influences trait expression, and whether or not the patterns are consistent across populations. In addition, to date no one has statistically investigated the possible age-sex interaction that may be influencing trait expression. Patterns of inter-trait association, age and sex effects on trait frequencies can also provide important clues to the etiology of particular features.

Smith's Mean Measure of Divergence is the most widely used statistic for non-metric trait distance analysis. Several adjustments can be applied to the equation but a comparison of the results indicates that they give closely similar results (Finnegan and Coopriider, 1978, Molto, 1983). The theoretical criticisms recently leveled against the MMD (Blangero and Williams-Blangero, 1991, 1993) must be addressed. Specifically, an alternative distance statistic needs to be devised which takes inter-trait correlation into account, and which appropriately reflects the assumption that presence/absence of a skeletal variant represents a threshold imposed on an underlying continuous liability. Then, the superior performance of this distance measure over MMD needs to be demonstrated in an actual population study. Its perceived theoretical weaknesses notwithstanding, the MMD has proven advantages in terms of computational simplicity,

maximum use of small fragmentary samples, and many published precedents for credible results with its use.

The inconsistent performance of non-metric traits in deciphering biological relationships may well result from the use of inappropriate traits i.e. those having little or no genetic component. Many researchers have been “uncritical and unimaginative in copying trait lists from secondary sources” (Saunders, 1989:102). Moreover, precision and reliability in scoring traits has been seriously neglected since Anderson (1968) first stated that future success of this area of study depended on detailed descriptive protocols for each trait. This view has since been reiterated by Finnegan, (1978), Ossenberg, (1976) and Saunders (1978, 1989). Saunders (1989) suggests that these two deficiencies are to blame for the disappointing results of many studies using non-metric traits to decipher prehistoric population affinities.

Statement of Objectives

The objectives of this dissertation are to:

- 1) describe and review the literature on fourteen non-metric traits of the sternum and vertebral column,
- 2) demonstrate the use of logit modeling to study the effects of population group, age and gender on the frequency distribution of these traits in six large aggregate samples,
- 3) examine the patterns revealed by logit analysis as well as by inter-trait association coefficients for evidence which might contribute to our knowledge of the etiology and morphological significance of these variants.

- 4) **a) demonstrate a novel distance statistic, analogous to Mahalanobis D^2 , based on threshold values of the traits derived from their logit analysis; and b) compare a twelve-population group distance matrix thus computed with its corresponding matrix computed with the Mean Measure of Divergence,**
- 5) **examine the patterns of population affinities revealed by the logit and logit-based D^2 :**
 - a) **for evidence in support of current hypotheses pertaining to ethnogenesis in North America, and b) in terms of the potential of these traits for forensic applications.**

CHAPTER II: SAMPLES, TRAITS AND SCORING PROTOCOL

Choice and Organization of Samples

A major objective of this research is the application of logit modeling to analyze the effects of population group, age and sex, and their interactive effect on the pattern of trait distribution. Such an analysis requires large skeletal samples. Accordingly, the five largest series among the 12 shown in Table 1 were chosen: Aleut (N=178), Kodiak Island (N=121), Late Woodland Indian (N=227), White (N=199) and Black (N=197). A sixth aggregate, "Eskimo" (N=479), was created from the amalgamation of the Arctic/Inupiaq Eskimo, South Alaskan Eskimo and Saint Lawrence Island Eskimo samples shown in Table 1. The same six samples also were used to investigate inter-trait association.

Because logit values by trait and population group were required for the Mahalanobis distance formula, in addition to the six-sample set of models used for analysis of population, age and sex effects, a second set of models was created, for all 12 skeletal samples used in the distance analysis. The second set of logit models was of interest also in terms of its concordance with the first set.

The secondary focus of the research is population affinities and biological distance analysis. The 12 samples listed in Table 1 represent 10 geographical/linguistic groupings of Native Americans, along with a European-derived (U.S. White) sample and an African-derived (U.S. Black) sample as outgroup comparisons for Asian-derived Native Americans. Within this broad comparative framework certain questions related to the peopling of North America can be explored. In addition, the pattern of affinities of the

TABLE 1. Skeletal aggregates and samples by age and sex, and listed geographically from North to South.

Skeletal aggregates and samples	Male			Female			Total		
	Young	Old	Total	Young	Old	Total	Young	Old	Total
Arctic/Inupiaq Eskimo	25	68	93	18	79	97	43	147	190
Saint Lawrence Island Eskimo	6	39	45	9	44	53	15	83	98
South Alaskan Eskimo	34	61	95	29	67	96	63	128	191
Ingalik (Athabaskan)	5	16	21	5	16	21	10	32	42
Aleut	17	72	89	6	83	89	23	155	178
Kodiak Island	24	39	63	25	33	58	49	72	121
North Pacific Coast Indian	12	33	45	8	17	25	20	50	70
Plains Indian	15	42	57	11	26	37	26	68	94
Late Woodland Amerind ¹	72	72	144	29	54	83	101	126	227
Illinois Hopewell Indian	22	24	46	13	24	37	35	48	83
White	5	93	98	2	99	101	7	192	199
Black	23	73	96	27	74	101	50	147	197
Total	260	632	892	182	616	798	442	1248	1690

¹ Northern Mississippi Valley

three major racial groups represented here (European-White, African-Black and Asian-derived) will be investigated with a view to the potential of the traits for forensic applications.

The use of archaeologically retrieved skeletal samples to answer questions of biological relationships is problematic (Cadien et al., 1976). However, because this study focused on biological relationships at the broadest level, rather than on fine-grained regional or temporal questions, it is hoped that potential problems will be avoided.

The specific skeletal samples that contribute to the Arctic/Inupiaq Eskimo, South Alaskan Eskimo, Aleut, and Plains Indian aggregates are listed in Table 1a, 1b, and 1c, and 1d respectively. Table 2 contains provenience information when available and institution where the collection was studied.

The following section presents a general overview of each skeletal sample, summarized from references cited.

Samples

Arctic/Inupiaq Eskimo

The Sadlermiut series, from Southampton Island, is the most recent archaeological sample, dating from the winter of 1902-1903 when the inhabitants of the village succumbed to an epidemic following what may have been their first contact with Europeans (Merbs, 1983). The majority of material used in this study was collected by Collins in 1955, 1956, 1957 and 1975 and by Laughlin in 1959, and is curated at the Canadian Museum of Civilization, in Hull, Quebec. Preservation is excellent.

TABLE 1a. Samples included in the Arctic/Inupiaq Eskimo aggregate shown in Table 1.

Skeletal samples	Male			Female			Total		
	Young	Old	Total	Young	Old	Total	Young	Old	Total
Thule	13	12	25	6	16	22	19	28	47
Sadlermiut	12	27	39	12	42	54	24	69	93
Point Hope	0	29	29	0	21	21	0	50	50
Total	25	68	93	18	79	97	43	147	190

TABLE 1b. Samples included in the South Alaskan Eskimo aggregate shown in Table 1.

Skeletal sample	Male			Female			Total		
	Young	Old	Total	Young	Old	Total	Young	Old	Total
Nushagak River	6	7	13	7	9	16	13	16	29
Bristol Bay	2	2	4	0	2	2	2	4	6
Kuskokwim River	13	15	28	9	10	19	22	25	47
Yukon River	0	28	28	0	37	37	0	65	65
Nunivak Island	13	9	22	13	9	22	26	18	44
Total	34	61	95	29	67	96	63	128	191

TABLE 1c. Samples included in the Aleut aggregate shown in Table 1.

Skeletal sample	Male			Female			Total		
	Young	Old	Total	Young	Old	Total	Young	Old	Total
Umnak Island	0	29	29	1	29	30	1	58	59
Other Eastern	5	15	20	1	17	18	6	32	38
Kagamil Island	10	21	31	4	29	33	14	50	64
Other Central	2	7	9	0	8	8	2	15	17
Total	17	72	89	6	83	89	23	155	178

TABLE 1d. Samples included in the Plains Indian aggregate shown in Table 1.

Skeletal sample	Male			Female			Total		
	Young	Old	Total	Young	Old	Total	Young	Old	Total
Dakota, Assiniboin	15	5	20	11	4	15	26	9	35
Arikara	0	37	37	0	22	22	0	59	59
Total	15	42	57	11	26	37	26	68	94

TABLE 2 . Skeletal aggregates, samples, provenience and institution where the material was studied.

Skeletal aggregates and samples		Provenience	Location of curation
<i>Arctic/Inupiaq Eskimo</i>	Thule	1200-1600 A.D. (Utermohle, 1984)	CMC ¹
	Sadlermiut	Early twentieth century (Merbs, 1983)	CMC
	Point Hope	1400-1850 A.D. (Utermohle, 1984)	SI ²
<i>Saint Lawrence Island</i>		1600-1900 A.D. (Saunders, 1978)	SI
<i>South Alaskan Eskimo</i>	Nushagak River	1600-1900 A.D. (Saunders, 1978)	SI
	Bristol Bay	recent (Ossenberg, 1992)	SI
	Kuskokwim River	1600-1900 (Saunders, 1978)	SI
	Yukon River	broad time-depth (Saunders, 1978)	SI
	Nunivak Island	Late nineteenth-early twentieth century (Utermohle, 1984)	SI
<i>Ingalik (Athabaskan)</i>		1800-1900 A.D. (Heathcote, 1986)	SI
<i>Aleut</i>	Umnak Island	2000 B.C.-1000 A.D. (Ossenberg, 1992)	SI
	Other Eastern	broad time-depth (Saunders, 1978)	SI
	Kagamil Island	1500-1700 A.D. (Heathcote, 1986)	SI
	Other Central	time-depth variable or not documented	SI
<i>Kodiak Island</i>		1500 B.C.-1000 A.D. (Ossenberg, 1992)	SI
<i>North Pacific Coast Indian</i>		1500 B.C.-500 A.D. (Cybulski, 1992)	CMC
<i>Plains Indian</i>	Dakota, Assiniboin	Nineteenth century (Ossenberg, 1974)	SI, UA ³ , USD ⁴
	Arikara	1700-1750 A.D. (Merchant, 1973)	SI
<i>Late Woodland Amerind</i>		500.-1500 A.D. (Ossenberg, 1974)	SI, UT ⁵ , CMC, ROM ⁶ , UM ⁷
<i>Illinois Hopewell</i>		100 B.C.-100 A.D. (Ossenberg, 1974)	UI
<i>White</i>		contemporary	SI
<i>Black</i>		contemporary	SI

¹ Canadian Museum of Civilization, Hull, Quebec.

² Smithsonian Institution, Washington, D.C., USA.

³ University of Alberta, Edmonton.

⁴ University of South Dakota (W.H.Over Museum), Vermilion.

⁵ University of Indiana, Bloomington.

⁶ Royal Ontario Museum, Toronto.

⁷ University of Minnesota, Minneapolis.

The Thule sample, consisting of the Kamarvik and Silumiut sites, dates from approximately 1200 to 1600 A.D.. Both sites are located in the Northwest Hudson Bay area and were excavated during the Northwest Hudson Bay Thule Project (Utermohle, 1984). The skeletons are currently curated at the Canadian Museum of Civilization in Hull, Quebec. Preservation is poor, particularly for the male skeletons (Merbs, 1967).

The Point Hope material, excavated near the village of Tigara, is also considered to be Thule. Though dating is not firm, the author chose to follow Utermohle (1984) and err on the side of a more recent, or Historic Thule period, with dates ranging from 1400 to 1850 A.D.. This series was excavated by Collins in 1929 and was originally curated at the Smithsonian Institution. The collection has been repatriated and is no longer accessible for study. The burials were located on mounds and were in wooden boxes approximately two feet below the surface. This may account for the relatively good preservation that is characteristic of this collection.

Saint Lawrence Island Eskimo

Approximately ten of the individuals are from the Kukulik:Midden series which was collected by Geist from 1931 through to 1935. It is believed that these individuals were the victims of a famine that devastated the village during the winter of 1878-1879 (Utermohle, 1984). Collins is thought to have collected the remaining portion of the sample which dates from approximately 1600 to 1900 A.D. (Saunders, 1978). The individuals examined for the present study are curated at the Smithsonian Institution and are well preserved. However, their repatriation is underway, and they are no longer accessible to researchers.

South Alaskan Eskimo

This sample consists of sites from Nushagak River, Bristol Bay, Kuskokwim River, Yukon River and Nunivak Island. All sites probably date to sometime within the last three hundred years and were collected mainly by Hrdlicka from 1926 to 1936 (Saunders, 1978), though several skeletons may have been collected by Collins (Stewart, 1932). All of the South Alaskan Eskimo skeletal material is curated at the Smithsonian Institution. Stewart (1932:124) comments on the good preservation of the majority of skeletons.

Ingalik

This series was collected by Hrdlicka during his 1926 and 1929 Alaska expeditions. The burials were recent, dating from about 1800-1900 A.D., and were excavated from several village sites along the Yukon River and its tributaries, within the territory of Athabascan-speaking Indians, mainly Ingalik (Heathcote, 1986).

Aleut

The Aleut samples used in this study originate from sites located in the Eastern and Central portions of the Aleutian Island chain. The great majority of the skeletons were collected by Hrdlicka from 1936 to 1938 and are curated at the Smithsonian Institution. Most unequivocally early, the Umnak Island (Eastern section) material dates from 2000 B.C.-1000 A.D., while, the most unequivocally late, the Kagamil Island mummy caves material dates from about 1500-1700 A.D.. The material from the Shiprock mummy caves and shelters (Eastern section), also remains from Rat and Andreanov Island groups (Central section), likely represent a broad time range (Ossenberg, 1992; Saunders, 1978; Utermohle, 1984). The Smithsonian Institution's Aleut collection has been extensively

studied, probably as a result of the excellent preservation of most of the material, and the substantial number of juvenile and adolescent remains represented in the collection.

Kodiak Island

Only two of the three strata from the Uyak Bay site are used in the present analysis: early (Hrdlicka's "Blue") and middle (Hrdlicka's "Red"). These individuals are thought to represent a homogeneous group somewhat distinct from the most recent stratum which contains the ancestors of the contemporary Koniags (Ossenberg, 1992; Utermohle, 1984) who now reside on Kodiak Island. Hrdlicka excavated the Uyak Bay site during field seasons from 1931 to 1936 (Heathcote, 1986). The early strata date from about 1500 B.C. to 1000 A.D. (Ossenberg, 1992). Though this collection was originally curated at the Smithsonian Institution, in 1989 it was repatriated to the Koniags. The collection is no longer available for study (Bray and Killion, 1994). The relationship of pre-Koniag peoples, represented in remains from the lower and middle strata of the Uyak site, to the historically-known Koniag Eskimo (whose direct ancestors are represented in the upper stratum) and to Aleuts, Indians and other Eskimo had not been resolved (Bray and Killion, 1994; Dumond and Scott, 1991; Heathcote, 1986; Ossenberg, 1994; Utermohle, 1982, 1984; Utermohle and Merbs, 1979) at the time of repatriation of the entire Uyak site collection from the U.S. National Museum to the Koniags in October 1989 (Bray and Killion, 1994).

North Pacific Coast Indian

This collection originates from the Tsimshian area of Prince Rupert Harbour, the skeletal material was excavated from ten midden sites located near the mouth of the

Skeena River (Cybulski, 1992). Excavation of the sites began in 1966 as part of the North Coast Prehistory Project undertaken by the Canadian Museum of Civilization (MacDonald and Inglis, 1981). The initial excavations were conducted by Macdonald who continued working in the area until 1970 when Inglis replaced him as site director. The majority of excavations were complete by 1973 but from that time until 1987, sporadic excavation of skeletal material has taken place (Cybulski, 1996). Radiocarbon dating of associated artifacts indicates that the various sites were occupied from 3500 to 1500 B.P. (Cybulski, 1992). The preservation of this material is poor and this is reflected in the small sample sizes of some of the non-metric trait observations.

Plains Indian

The Plains Indian sample is an aggregate of three collections. The Historic Plains aggregate consists of a small sample of Dakota Sioux, collected mainly by surgeons of the U.S. Army at the time of the 19th century Plains Indian wars, and currently held in the Smithsonian Institution, and a small sample of Assiniboin from an historic cemetery in Alberta, curated at the University of Alberta (Ossenberg, 1974). The Arikara sample was excavated in 1971 by Ubelaker and is from the Mobridge site in North Dakota. It is believed that the village was occupied from approximately 1700 to 1750 A.D. (Merchant, 1973). The Arikara material is curated at the Smithsonian Institution and preservation ranges from poor to good. It is currently undergoing final processing for repatriation and is no longer accessible to researchers.

Late Woodland Indian

This series is an aggregate of skeletal samples excavated from many burial mounds scattered throughout the northern Mississippi Valley drainage. This large area (also called the northeastern Plains periphery) includes southern Manitoba, Minnesota, and adjacent parts of North and South Dakota. The mounds were excavated between the years 1870 and 1960 by various individuals and institutions. Based on artifacts and cultural inferences the mounds are grouped into eight archaeological complexes dating roughly from about 500 to 1500 A.D. Their cranial morphology, metric and non-metric, supports the hypothesis that these prehistoric people were ancestral to the historic tribes of the Northern Plains (Ossenberg, 1974, 1992).

Illinois Hopewell Indian

Excavated from the Klunk II and Wilson burial mounds belonging to the Classic period, 100 B.C.-100 A.D., these remains were studied by N.S.Ossenberg in the Laboratory of Bioanthropology, University of Indiana (Ossenberg, 1974). These Middle Woodland people had a subsistence economy based on agriculture, in contrast to other Amerindian peoples represented in this study who were hunter-gatherers.

White and Black

The White and Black samples are derived from the Terry collection which is permanently curated at the Smithsonian Institution. The material was originally accessioned at the Washington University School of Medicine and was collected by R.Terry, in St. Louis, during the interval from 1910 to 1940. Most individuals in the sample were born in the late nineteenth or early twentieth century, and age and sex

information is available for each skeleton. Though some admixture with Whites is probable for the Black sample (Corruccini, 1974:426), it is not deemed significant enough to obscure the differences between the two groups. Not surprisingly, most skeletons are complete and well preserved.

Data Collection and Preparation

Trait list

The initial trait list and scoring protocol were developed by N.S.Ossenberg who trained me immediately prior to the commencement of data collection at the Canadian Museum of Civilization in July, 1994. A total of 35 unilateral and bilateral traits of the vertebral column were examined and recorded. Both the left and right side were examined if the trait could be expressed bilaterally. While some traits were binary (scored as either “present” or “absent”) a number were polychotomous; i.e. scored on a graded scale. For example, the trait *number of sacral units* included categories for four, five, six and seven sacral vertebrae. If the bone was missing or damaged in the relevant area, the trait was scored as “unobservable”.

The data were derived from skeletal samples examined by the author during the summers of 1994 and 1995 at the Canadian Museum of Civilization, Hull, Quebec, and the Smithsonian Institution, Washington, D.C., respectively. In addition though it had not been analyzed, a substantial database was on hand from skeletal samples examined by N.S.Ossenberg at various institutions since 1963. Table 3 indicates which researcher was responsible for recording the associated data, by skeletal sample.

TABLE 3. Skeletal aggregates, samples and data recorders.

Skeletal aggregates and samples		Data recorder
<i>Arctic/Inupiaq Eskimo</i>	Thule	author
	Sadlermiut	author
	Point Hope	NSO
<i>Saint Lawrence Island Eskimo</i>		author/NSO ¹
<i>South Alaskan Eskimo</i>	Nushagak River	author/NSO*
	Bristol Bay	author/NSO*
	Kuskokwim River	author/NSO*
	Yukon River	author
	Nunivak Island	author/NSO*
<i>Ingalik (Athabaskan)</i>		author
<i>Aleut</i>	Umnak Island	author
	Other Eastern	author
	Kagamil Island	author
	Other Central	NSO
<i>Kodiak Island</i>		NSO
<i>North Pacific Coast Indian</i>		NSO
<i>Plains Indian</i>	Dakota, Assiniboin	NSO
	Arikara	author
<i>Late Woodland Amerind</i>		NSO
<i>Illinois Hopewell Indian</i>		NSO
<i>White</i>		author
<i>Black</i>		author

¹ The author scored 59 skeletons and NSO scored 39 skeletons.

* The author rescored S₁ lumbarization, six unit sacrum, S₁ cleft neural arch and high sacral hiatus. See text for further details.

It should be noted that as a result of the change in scoring protocol for S_1 lumbarization, the author rescored this trait (in addition to *six unit sacrum*, S_1 cleft neural arch and *high sacral hiatus*) while at the Smithsonian Institution during the summer of 1995. In the South Alaskan Eskimo sample the author rescored all Bristol Bay skeletons; 21 of 29 Nushagak River skeletons; 40 of 47 Kuskokwim River skeletons; and 29 of 44 Nunivak Island skeletons, and in the Saint Lawrence Island Eskimo sample the author rescored all skeletons originally scored by N.S.Ossenberg. For practical and financial reasons it was not possible to re-examine the *lumbosacral junction* of skeletal collections curated elsewhere (see Table 3).

The following 14 features (from the original list of 35 features) of the sternum and vertebral column were analyzed:

- | | |
|---|--|
| 1) <i>Sternal aperture</i> | 8) <i>Cervical rib</i> |
| 2) <i>Atlas bridge, posterior</i> | 9) <i>L₁ anticlinal unit</i> |
| 3) <i>Atlas bridge, lateral</i> | 10) <i>Lumbar rib</i> |
| 4) <i>Atlas transverse foramen defective</i> | 11) <i>Six unit sacrum</i> |
| 5) <i>Axis transverse foramen defective</i> | 12) <i>S₁ lumbarization</i> |
| 6) <i>C₆ double transverse foramen</i> | 13) <i>S₁ cleft neural arch</i> |
| 7) <i>C₇ costal transverse foramen</i> | 14) <i>High sacral hiatus</i> |

Identification of vertebrae

One of the greatest challenges that accompanies skeletal research of the vertebral column is the difficulty in identifying, with certainty, the correct position of each vertebra in the column. This is particularly problematic if the vertebral column is incomplete. Fortunately, the majority of vertebral columns examined at both the Canadian Museum of Civilization and the Smithsonian Institution were stored as articulated units. Otherwise,

when sufficient number of loose vertebrae were available, an attempt was made to articulate the column based both on morphological criteria, size and fit.

Age and sex estimates

Age estimates were based on museum records, epiphyseal union and tooth wear, and in the case of the Thule and Sadlermiut samples, on estimates kindly provided by Dr. Charles Merbs of Arizona State University. The following ten categories were used: 0-5, 6-8, 9-11, 12-15, 16-20, 21-29, 30+, child, adolescent, adult.

Sex estimates were based on museum records, pelvic and cranial morphology, and in the case of the Thule and Sadlermiut samples, on estimates kindly provided by Dr. Charles Merbs of Arizona State University. Five categories were used: male, probable male, female, probable female, indeterminate.

Database

Data were entered into Paradox for Windows, version 5.0 (1994) with samples from various geographical/racial groups stored in separate files. In addition, N.S.Ossenberg's existing database was altered to reflect my rescoring of the following four traits: *S₁ lumbarization*, *six unit sacrum*, *high sacral hiatus*, and *S₁ cleft neural arch*. Finally a "master" database file was created by amalgamating all files to be used in the analysis.

Specific data were extracted from the "master" file for the present research. The master file remains intact and available for future research, particularly as a means of exploring questions that arise from the current analysis.

Two customized database files were created for each of the two analyses. The one for the analysis of population group, age, sex and inter-trait association effects is comprised of

data for six aggregate geographic/racial samples (Eskimo, Aleut, Kodiak Island, Late Woodland Indian, Black, and White), while that for the distance analysis has data for twelve geographic/racial samples (Arctic/Inupiaq Eskimo, Saint Lawrence Island Eskimo, South Alaskan Eskimo, Ingalik, Aleut, Kodiak Island, North Pacific Coast Indian, Plains Indian, Late Woodland Indian, Illinois Hopewell Indian, White and Black). In addition, the following adjustments were made:

- 1) The initial list of 35 traits was reduced to 14 traits. Those that were discovered to be a) difficult to score consistently (e.g., *ossified apical ligament*), b) too rare for statistical analysis (e.g., *cleft neural arch of C₁ and T₁₂*), c) influenced by mechanical stress relating to subsistence activities (e.g., *spondylolysis*) or d) redundant (e.g., *double transverse foramen C₃ to C₅*) were eliminated. A detailed review of each of the 14 traits appears in the following section.
- 2) In order to facilitate statistical analysis, data for graded and multinomial traits were renamed and regrouped to correspond to dichotomous traits. For example, the trait *number of sacral units* became *six unit sacrum* and individuals with a *six unit sacrum* were scored as having the trait present, while all others were scored as having the trait absent.
- 3) Data for individuals younger than twenty years of age were eliminated. Though insufficient data were available for analysis of subadult-adult differences, previous research (Corruccini, 1974; Korey, 1970; Ossenbergl, 1969; Saunders, 1978) already documents that a number of non-metric traits are affected by childhood and adolescent growth. It is less clear whether and to what extent non-metric traits are affected by

adult age changes. Accordingly, the differences between two adult cohorts were analyzed: “young adult” (21-29 years of age) or “old adult” (30 years of age and older).

- 4) Data for individuals of indeterminate sex were eliminated. Those that were classified as “probable male” or “probable female” were reassigned as “male” and “female” respectively.
- 5) Data from the right side of those traits that occur bilaterally were excluded from most of the analysis. The debate concerning the use of side versus individual for calculating trait frequencies has not been resolved, and is beyond the scope of the present study (see Konigsberg, 1987:102-107, for an excellent assessment of this topic). Following Konigsberg (1987), data from only one side of the body were used (left side) for logit modeling. However, in calculation of the Mean Measure of Divergence, total left plus right side frequencies were used.

In summary, two specific databases were created from the “master” database. The first, to be used in the analysis of the effects of population group, age, sex and inter-trait correlation on non-metric trait frequency, has data for six geographical/racial samples while the second, to be used in the distance analysis, has data for twelve samples. Both contain presence/absence data for 14 binary traits. Each individual is assigned to one of two sexes (male or female), and one of two adult age groups (young or old).

Finally, both databases were exported for analysis in SAS System for Windows, version 6.10 (1993).

Observer Replicability

When data are collected by a single observer at various intervals over an extended period of time, or by two or more observers, scoring consistency must be assessed (Molto, 1979; Suchey, 1975). To date, few studies have addressed the issue of inter- and intra-observer agreement within the context of non-metric trait research. Exceptions include De Stephano et al. (1984), Molto (1979) and Saunders (1978).

Statistical analysis

The phi coefficient was used in this study to analyze inter and intra-observer agreement in the scoring of non-metric traits of the vertebral column. Because phi measures the extent of association between two dichotomous variables, it is ideal when traits are binary, i.e. scored as present or absent, and when comparing the observations of no more than two individuals (Siegel and Castellan, 1988).

Phi is expressed as an association coefficient and is calculated from a 2-by-2 contingency table arranged as follows:

		Variable A	
		A ₁	A ₂
Variable B	B ₁	n ₁₁	n ₁₂
	B ₂	n ₂₁	n ₂₂

where A₁ and A₂ represent observer A's scoring for trait presence and absence respectively and B₁ and B₂ represent observer B's scoring for trait presence and absence respectively.

The formula for calculating the phi coefficient is expressed as:

$$\hat{\phi} = \frac{n_{11}n_{22} - n_{12}n_{21}}{\sqrt{n_{1+}n_{2+}n_{+1}n_{+2}}}$$

and will range from -1 to +1 with zero indicating no association between variable A and variable B. Phi is sensitive to marginal distributions, and skewness of one or both variables will decrease its magnitude (Reynolds, 1977:31). A corrected phi can be calculated by dividing the original phi by “phi maximum” which is calculated as the maximum value that phi can achieve given the observed marginal distributions (Willemsen, 1973). Because the phi coefficient is proportional to X^2 , the Pearson chi-square statistic, $X^2 = n_{++}\hat{\phi}^2$, the X^2 test statistic can be used to test $H_0 : \phi = 0$. This test will indicate whether the observed association is due to a real relationship between the scorings or due to chance. Obviously, there should always be a statistically significant association between repeated observations of the same item, so that the test of significance is not important. Rather, the phi coefficients are used to measure the *degree* of association between the observations.

Skeletal samples

Inter-observer tests were conducted on the Aleut skeletal sample curated at the Smithsonian Institution in Washington, D.C. The data were collected by N.S.Ossenberg in 1963 and by the author in 1995. Ninety-eight individuals were examined but not all traits were observable on each skeleton thus sample size varies by trait. For bilaterally expressed traits observations from the left and right side were combined in order to increase sample size.

Intra-observer tests were conducted on 50 randomly selected Sadlermiut skeletons curated at the Canadian Museum of Civilization in Hull, Quebec. Data were collected in August 1994 and December 1995. Not all traits were observable on each skeleton, and left and right sides were combined for bilaterally expressed traits in order to increase sample size.

Results

Table 4 lists phi coefficients, phi maximum coefficients, and corrected phi coefficients, for the inter-observer agreement tests. Two traits showed perfect agreement between observers: *sternal aperture* and *atlas bridge posterior*. Eight traits had phi coefficients between 0.825 and 0.995 while *lumbar rib* and *six unit sacrum* had phi coefficients of 0.741 and 0.720 respectively. *Axis transverse foramen defective* and *S₁ lumbarization*, had the lowest phi coefficients, 0.586 and 0.432 respectively. When corrected phi coefficients were calculated, six traits indicated perfect association, while the remainder ranged from 0.737 to 0.929. The exception was *axis transverse foramen defective* which remained the same at 0.586.

Table 5 lists phi coefficients, phi maximum coefficients, and corrected phi coefficients, for the intra-observer agreement tests. *Sternal aperture*, *atlas bridge lateral* and *posterior*, *axis transverse foramen defective* and *C₆ double transverse foramen*, all indicated perfect association. The remaining nine traits scored above 0.759 with the highest association between observations being *cervical rib* with a phi coefficient of 0.9873, and the lowest being *S₁ lumbarization* with a phi coefficient of 0.7589. When the corrected phi coefficients were calculated 10 traits showed perfect association, while the remaining four, *S₁ lumbarization*, *L₁ anticlinal unit*, *lumbar rib* and *S₁ cleft neural arch*

TABLE 4. Phi and corrected phi coefficients for inter-observer agreement analysis. "O" is NS Ossenberg and "W" is author.

Trait	O and W Present		O and W Absent		O present		W present		phi	
	Present	Absent	Present	Absent	O present	W present	O absent	W absent	max	corrected
<i>Sternal aperture</i>	1	30	0	0	1.000	1.000	0	0	1.000	1.000
<i>Atlas bridge posterior</i>	15	133	3	3	0.870	0.936	1	1	0.870	0.929
<i>Atlas bridge lateral</i>	15	135	0	0	1.000	1.000	0	0	1.000	1.000
<i>Atlas transverse foramen defective</i>	7	140	3	3	0.825	0.825	0	0	0.825	1.000
<i>Axis transverse foramen defective</i>	3	128	2	2	0.586	1.000	2	2	0.586	0.586
<i>C₆ double transverse foramen</i>	49	73	3	3	0.888	0.984	4	4	0.888	0.902
<i>C₇ costal transverse foramen</i>	8	88	2	2	0.884	0.884	0	0	0.884	1.000
<i>Cervical rib</i>	0(1)	76	1	1	0.995	0.995	0	0	0.995	1.000
<i>L₁ antitlinal unit</i>	13	50	1	1	0.832	0.918	3	3	0.832	0.907
<i>Lumbar rib</i>	10	92	2	2	0.741	0.916	4	4	0.741	0.809
<i>Six unit sacrum</i>	19	33	3	3	0.720	0.932	5	5	0.720	0.773
<i>S₁ lumbarization</i>	21	80	4	4	0.432	0.587	33	33	0.432	0.737
<i>S₁ cleft neural arch</i>	7	62	2	2	0.868	0.932	0	0	0.868	0.773
<i>High sacral hiatus</i>	2	67	1	1	0.868	0.868	0	0	0.868	1.000

TABLE 5. Phi and corrected phi coefficients for intra-observer agreement analysis.

Trait	'94 And '95 Present	'94 And '95 Absent	'94 Present '95 Absent	'95 Present '94 Absent	phi	phi max	phi corrected
<i>Sternal aperture</i>	2	31	0	0	1.000	1.000	1.000
<i>Atlas bridge posterior</i>	1	105	0	0	1.000	1.000	1.000
<i>Atlas bridge lateral</i>	2	104	0	0	1.000	1.000	1.000
<i>Atlas transverse foramen defective</i>	4	99	0	2	0.808	0.808	1.000
<i>Axis transverse foramen defective</i>	1	105	0	0	1.000	1.000	1.000
<i>C₆ double transverse foramen</i>	36	59	0	0	1.000	1.000	1.000
<i>C₇ costal transverse foramen</i>	18	62	0	8	0.783	0.783	1.000
<i>Cervical rib</i>	0 (1)	39	1	0	0.987	0.987	1.000
<i>L₁ anticlinal unit</i>	18	28	1	3	0.837	0.920	0.909
<i>Lumbar rib</i>	19	60	1	6	0.800	0.860	0.930
<i>Six unit sacrum</i>	18	24	5	0	0.806	0.806	1.000
<i>S₁ lumbarization</i>	75	60	15	4	0.759	0.865	0.878
<i>S₁ cleft neural arch</i>	7	43	1	1	0.852	0.855	0.997
<i>High sacral hiatus</i>	4	46	2	0	0.799	0.799	1.000

ranged from 0.878 to 0.997 respectively.

Discussion

For both inter and intra-observer agreement tests, 10 traits scored above 0.8. *Axis transverse foramen defective* and *six unit sacrum* were below in the former, *C₇ costal transverse foramen* and *high sacral hiatus* were below in the latter and *lumbar rib*, and *S₁ lumbarization* were below in both tests. In regards to the inter-observer agreement tests, it is important to note that N.S.Ossenberg examined the Aleut skeletal material more than 30 years before she trained the author in scoring protocol. Some variation between observations may be attributed to changes in protocol or systematic recording bias that occurred during this long interval. N.S.Ossenberg's intra-observer agreement analysis, to be conducted on the same skeletal sample as the current inter-observer agreement analysis, will be examined to determine the extent to which this may be a contributing factor.

Comments pertaining to the traits that had phi coefficients (not corrected) of less than 0.8 are required. The poor performance of *S₁ lumbarization*, particularly for the inter-observer agreement test, was expected by the researchers. In 1994 N.S.Ossenberg changed her protocol for scoring *S₁ lumbarization* to a graded system. The new protocol included separate categories for absent, weak, medium, strong and complete lumbarization, while the previous protocol included separate categories for absent, signs, and complete. It seems likely that with the addition of a category specifically for "weak lumbarization", a less severe manifestation of the trait that would previously have been scored as absent, would now be scored as "weak lumbarization". Close examination of the data indicated that this was the case. Fourteen of the 16 sacra which the author scored

as weak lumbarization using the new protocol, N.S.Ossenberg scored the trait as absent using the old protocol. In view of this analysis of lack of agreement, we decided that for this trait only the data collected by the author would be used in the population group, age, sex and inter-trait association analysis. Further, we decided to exclude this feature from the distance analysis.

Lumbar rib was also anticipated to be problematic. Scoring this trait as present is usually based on the identification of an articular facet on the first lumbar vertebra. As mentioned above, this can be difficult because the facet is variable in size, shape and location; also damage to the bone or a build-up of dirt can mask its presence. As these factors became more apparent, during the initial phases of data collection, I became more diligent in examination for evidence of the trait. Not surprisingly, a systematic scoring bias is reflected in the 1995 data: 25 lumbar ribs were scored in 1995, 20 in 1994. The inter-observer agreement analysis also indicated that this trait is difficult to score consistently but the discrepancy was not nearly as large. Inter-observer phi coefficient was close to 0.8 with a value of 0.741. Inconsistency probably resulted from factors previously mentioned: bone destruction and dirt.

Detecting the presence of a *costal transverse foramen* on the seventh cervical vertebra poses a similar problem, as damage and dirt build-up may obstruct the relevant area. Secondly, though the larger costal transverse foramina are clearly present, those that are small can be ambiguous if the surrounding bone is porous. A third factor may relate to orientation of the foramen; i.e. if it is small, slit-like (rather than round or oval), and

oriented more in the coronal than in the horizontal plane, it could escape detection depending on the angle at which one observes the specimen.

The phi coefficient indicates substantial inter-observer agreement (.884) and questionable intra-observer agreement (.783). This trait was scored as present eight more times in 1995 than in 1994, which indicates systematic scoring bias. The reason for the shift is not clear.

High sacral hiatus had a phi coefficient of 0.799 for the intra-observer agreement test. Because the phi value was close to 0.8 in this case and was high (.868) for the inter-observer agreement test, scoring replicability was considered acceptable.

Axis transverse foramen defective was expected to pose no difficulties in scoring consistency. This was the case for intra-observer agreement in which association was 100%, but not for inter-observer agreement in which the phi coefficient and corrected phi (.586 in both cases) were low. Both observers scored the trait as present five times out of 135 but only three of the the five individuals were scored as present by both observers. N.S.Ossenberg scored the trait as present in two individuals in which the author scored the trait as absent and the author scored the trait as present in two individuals in which N.S.Ossenberg scored the trait as absent. Despite the scoring discrepancy, the total frequency count for axis transverse foramen defective would be the same (i.e. 5/135).

Inconsistency between observers in scoring *six unit sacrum* is puzzling. The trait has the potential of being ambiguous if the observer is required to determine whether or not the extra sacral segment is a fused coccygeal vertebra. The protocol developed for this study was intended to eliminate this problem by counting the total number of vertebrae

incorporated into the sacrum without consideration of the number of units in contiguous regions of the spine. However, close examination of the data indicated disagreement for eight individuals; in three cases the trait was scored present by N.S.Ossenberg and absent by the author, while in five cases the disagreement was reversed. Future re-examination of these specimens could clarify the cause of the discrepancy.

Summary

For both inter and intra-observer agreement tests, 10 of the 14 traits scored above 0.8 which was deemed an acceptable level of agreement. Those that scored below 0.8 were investigated in an attempt to determine the cause of the poor performance. While the reasons were fairly apparent in certain cases, for two traits (*axis foramen defective* and *six unit sacrum*) there seemed to be no explanation for the poor inter-observer agreement.

Trait Description

Sternal aperture

This trait is defined as a perforation in the sternum, usually occurring in the midline between the third and fourth sternebrae. The defect can be oval or round, large or small and the edges are smooth from the anterior to posterior surface (Figure 1). Rarely, apertures have been observed in the manubrium and in multiples in the sternal body (Ashley, 1956; Cooper et al., 1988). Microscopic examination of the contents of six sternal apertures, removed during autopsy, indicates that only fibroadipose tissue and small vessels fill the gap in the bone (Cooper et al., 1988). The trait is visible on

FIGURE 1. Anterior view of sternum showing sternal aperture.

0 5 cm

NMNH 1324

NMNH 31K

roentgenograms and might be mistaken for a wound. However, as it is completely asymptomatic it has not been the subject of clinical research.

Embryology. The sternum forms from two mesenchyme bands which grow toward each other, and progressing from cranial to caudal, unite along the midline by the 10th week of fetal development. Shortly after the sternal bands have fused they unite with (and are subsequently influenced by) the ribs and segmentation is initiated. Before the sternal bands unite, chondrification begins within their mesenchyme tissue and by the 5th fetal month ossification begins. The number and location of ossification centres dictate the morphology of the sternum (Ashley, 1956; Barnes, 1994). In turn, these centres vary depending on the developmental timing of the fusion of the sternal bands and subsequent chondrification (Barnes, 1994). Of the patterns that have been observed, the following two occur most frequently:

- 1) The first and second sternebrae form from a single midline ossification centre, and the third and fourth form from paired, bilateral ossification centres. This results in what is considered normal sternal form i.e. the body is slightly wider inferiorly than superiorly.
- 2) Each of the four sternebrae develop from a single midline ossification centre, resulting in a narrow, parallel-sided sternum.

Less frequently each of the four sternebrae may develop from paired, bilateral ossification centres, resulting in a broad, rounded sternum (Barnes, 1994; McCormick and Nichols, 1981). Barnes (1994) states that the final form of the sternum (and presumably the process that leads to this form) is genetically determined.

A sternal aperture results if chondrification is complete before unification of the sternal bands at the caudal end (Barnes, 1994). This is because when the mesenchyme tissue of the sternal bands becomes cartilaginous, it loses its ability to fuse, resulting in a gap in the area where fusion has not yet occurred. The size and shape of the defect depends on the timing of the delay in fusion (Barnes, 1994). As Ashley (1956:88) originally argued,

..it is apparent that the presence or absence of a sternal foramen is determined *in the pre-ossification stage of development*, i.e. when the sternum is still cartilaginous. Therefore 'defective ossification' is the *result* not the *cause* of a sternal foramen (italics in original).

It should be noted that some researchers maintain that the sternal aperture results from a defect in ossification (Cooper et al., 1988; McCormick, 1981), but have not proposed a mechanism by which this could occur, or explained why the gap is not filled with cartilage as would be expected if development was normal up to and including chondrification.

Population frequency. There is evidence that the frequency of sternal aperture varies among populations. Though no statistical analysis was conducted, McCormick (1981) found that Blacks accounted for 52% (13/25) of the cases exhibiting the defect, even though they comprised only 35% (113/324) of the total sample. Ashley (1956) also found a higher frequency in Blacks (east Africans), at 13%, than Europeans, at 4%. Anderson (1963) reported a frequency of 10% in a sample of Ontario Iroquois, while Saunders (1978) reported a frequency of only 2.7% in a mixed sample of Eskimos and Aleuts.

Age and sex effects. The developmental processes leading to the formation of a sternal aperture suggest that the trait is age stable. By six years of age, the adult form of the sternum is determined (McCormick and Nichols, 1981); accordingly, the defect would be

manifest by this time. The trait has been reported in children as young as eight (Cooper et al., 1988), and in all adults up to 88 years of age (McCormick, 1981).

Finally, several researchers have reported that the sternal aperture occurs twice as often in males as in females (Ashley, 1956; McCormick, 1981). The difference may be related to size: the greater the divergence between the two sternal bands when chondrification begins, the greater the probability of developing a sternal aperture.

Scoring protocol. This trait was scored as present or absent. In the case of a partial (fragmentary) specimen displaying an aperture the trait was scored as present, whereas when no aperture was visible, the trait was scored as unobservable.

Because the sternal aperture is easily identified and recorded, inter and intra-observer agreement should be high. In both cases the phi coefficients indicate perfect association.

Atlas bridge posterior

The posterior atlas bridge is a bony growth extending from the superior articular process to the posterior arch just posterior to the vertebral artery sulcus (Figure 2). En route to the foramen magnum, the vertebral artery ascends through the transverse foramen of the atlas, and curves posteriorly and medially to lie in its sulcus. When a bony bridge spans the sulcus, it forms a foramen for the vertebral artery that can be shallow or deep, depending on the morphology of the sulcus itself. In addition, as the first cervical nerve leaves the spinal cord, it also traverses the foramen created by the atlas bridge.

The posterior bridge may be complete or incomplete. However, the latter expressions (spurs) were not counted as trait present in this study as a result of being difficult to score consistently (Saunders, 1978). The bony bridge has been variously named ponticulus

posticus, Kimmerles anomaly, the spiculum and posterior glenoid process. The foramen formed by the bridge has been called foramen arcuale or foramen retro-articular superior (Von Torklus and Gehle, 1972).

Etiology. The origin of the posterior bridge is not clear. Earlier anatomist (e.g. Ossenfort, 1926), believed that it is a primitive feature, representing the superior oblique process that occurs over the vertebral artery in “lower” mammals. Epstein (1976) and Pyo and Lowman (1959) believe that it represents late ossification of the posterior segment of the atlanto-occipital ligament, but provide no explanation as to how or why it occurs in children. Taitz and Nathan (1986) agree with this hypothesis but concede that because it has been observed in relatively young individuals, other factors may be of importance. Von Torklus and Gehle (1972) suggest that the posterior bridge is a manifestation of the fourth occipital vertebra and represents a cranial shift at the occipitocervical border, while Barnes (1994) speculates that it could result from “occipitalization” of the atlas, which represents a caudal shift at the occipitocervical border. Following an investigation of a skeletal sample comprising both American Black and White males Lanier (1939) observed that complete bridging occurred in 19% of vertebral columns exhibiting cranial shift and 12% of vertebral columns exhibiting caudal shift.

Because it is visible by clinical x-ray, the frequency and distribution of the posterior bridge has been well studied in living populations. Of particular note is the work of Selby and colleagues (1955) and Saunders and Popovich (1978). Both studies are based on a large series of x-rays, the former derived in conjunction with a longitudinal growth study conducted in Ohio, the latter derived in conjunction with a longitudinal growth study

conducted in Burlington, Ontario. The participants included children, parents, siblings and other relatives. Selby et al. (1955) found that 52% of siblings and 48% of parents of affected children exhibited the trait, while Saunders and Popovich (1978) found that 40% of siblings and 44% of parents of affected children exhibited the trait. These were significantly higher proportions than observed in the study sample. In addition, Saunders and Popovich reported that the father-offspring and mother-offspring correlations were significant, while the father-mother correlation was not. The familial nature of the atlas posterior bridge is indisputable and clearly indicates that this is a genetically based trait.

Population frequency. Population frequencies for complete posterior bridge range from 2% in East Indians to 13% in U.S. Blacks, with U.S. and Canadian Whites ranging from 9% (Saunders and Popovich, 1978; Taitz and Nathan, 1986) to approximately 12 % (Ossenfort, 1926). Ma (1993) reported a frequency of 7% in a combined Eskimo-Kodiak skeletal sample and 12% in a combined Amerind-Aleut skeletal sample.

Age and sex effects. Complete atlas bridging is usually reported to occur more often in males than females (Ma, 1993; Ossenfort, 1926; Romanus and Tovi, 1964; Saunders and Popovich, 1978; Selby et al., 1955) which is expected as it is categorized as an hyperostotic (excess bone growth) trait. Alternatively, Taitz and Nathan (1986) report it to be more common in females based on their examination of a large skeletal sample of White Americans, while Saunders (1978) found no statistically significant difference between the two sexes in an Amerind skeletal sample and an Eskimo-Aleut skeletal sample.

The ratio of complete to incomplete posterior bridging increases with increasing age suggesting that the trait is influenced by age changes. Again, this is expected as it is categorized as an hyperostotic trait. Nevertheless, complete bridging has been observed in individuals as young as six (Selby et al., 1955), and partial bridging has been observed in relatively old individuals, indicating that manifestation of a partial bridge is not simply a developmental precursor of a complete bridge. When only adults were considered, Saunders (1978) found no significant age differences between young and old age groups in two Amerind skeletal samples and a combined Eskimo-Aleut skeletal sample.

Scoring protocol. Complete posterior bridge was scored as present while partial and absent bridges were scored as absent. If a complete bridge was observed on a fragmented atlas it was scored as present, but if it was not clearly absent it was scored as unobservable.

When “trait present” is restricted to complete posterior bridge this trait is easily identified and recorded. The phi coefficients reflect this with intra-observer agreement perfect and inter-observer agreement of 0.870.

Atlas bridge lateral

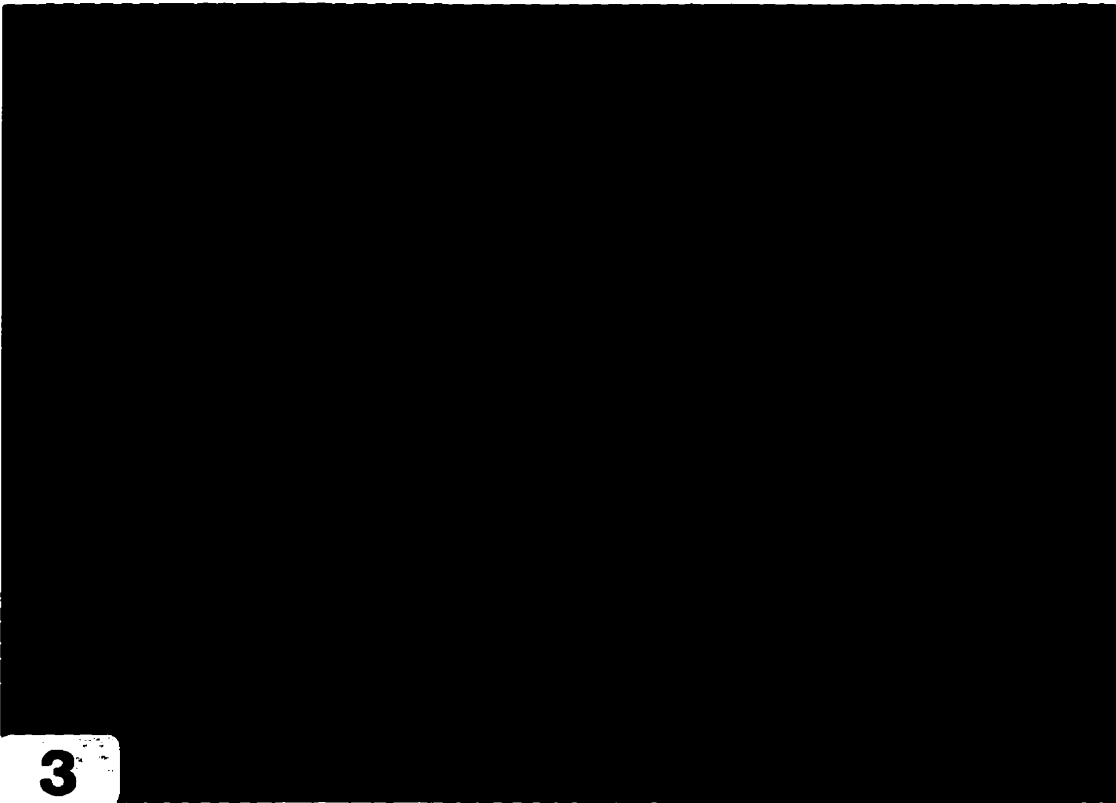
The lateral atlas bridge is a bony growth that extends laterally from the superior articular process to the transverse process (Figure 3). Occasionally a complex structure is formed when a third bridge joins the lateral bridge to the posterior bridge. During life, the vertebral artery, as it emerges from the foramen transversarium, would pass below this bridge. The bridge may be complete, or expressed partially as bony spurs. However, the

FIGURE 2. Superior view of first cervical vertebra showing atlas bridge posterior.

FIGURE 3. Posterior view of first cervical vertebra showing atlas bridge lateral.



2



3

partial expressions are difficult to score consistently (Saunders, 1978) and were counted as trait absent in this study.

Population frequency. The trait has not been adequately studied because it is not readily detectable by x-ray and is relatively rare. Nonetheless, there is evidence that it varies between populations. Taitz and Nathan (1986) report a frequency of 3% in a skeletal sample of East Indian, Middle Eastern and U.S. Black and White individuals, while Ma (1993) reports a frequency of 7% in a sample of Eskimo and Kodiak skeletons, and 11% in a sample of Amerind and Aleut skeletons.

Age and sex effects. In Ma's (1993) Eskimo-Kodiak sample, males exhibited the trait twice as often as females ($X^2=4.91$; $p=0.03$), while in the Amerind-Aleut sample, male and female frequencies were almost identical ($X^2=0.09$; $p=0.77$). It is not clear whether there is an adult age effect for complete lateral bridging because, of the tests that have been conducted, many combined males and females, considered both partial and complete manifestation of the trait, and pooled various age groups.

Inter-trait correlation. It should be noted that both Saunders (1978) and Buikstra (1972) found that lateral atlas bridge was correlated with posterior atlas bridge. Saunders (1978) pooled her data and calculated a frequency for "atlas bridging", while Buikstra (1972) eliminated the lateral bridge trait from her analysis. Taitz and Nathan (1986:216) found that "the presence of a lateral bridge is not always associated with posterior bridge", though no tests were conducted to determine statistical significance of this observation.

Scoring protocol. Complete lateral bridge was scored as present while partial and absent lateral bridges were scored as absent. If a complete bridge was observed on a fragmented

atlas, it was scored as present, but if it was not clearly absent, it was scored as unobservable.

As is the case for posterior bridge, intra and inter-observer agreement are expected to be high when complete lateral bridge is scored as present and partial lateral bridge is scored as absent. The phi coefficients indicate perfect association in both cases.

Defective atlas and axis transverse foramina

When the costal portion of the transverse process of the atlas or axis vertebrae does not develop, or is underdeveloped, the result is an open transverse foramen, referred to as *transverse foramen defective* in this study (Figures 4 and 5). Normally, during early childhood development, the costal portion fuses with the remainder of the transverse process and creates the foramen for passage of the vertebral artery. This defect occurs most often in the atlas and axis vertebrae and its presence in these two vertebrae may be correlated.

Etiology. The origin of the trait is not clear, most likely because it has not yet been the focus of a significant amount of research. There appear to be no clinical symptoms associated with the defect.

Population frequency. Ossenfort (1926) reported a frequency of 6% in the atlas of U.S. Blacks and 9% in the atlas of U.S. Whites, while Saunders (1978) reported an average frequency of approximately 5% in both vertebral types of an Eskimo-Aleut and an Amerind skeletal sample. Lanier (1939:405) stated,

Most of the minor variations of the cervical vertebrae, such as doubled and incomplete transverse foramina appear not to be associated with heredity and race,

FIGURE 4. Superior view of first cervical vertebra showing atlas transverse foramen defective.

FIGURE 5. Lateral view of second cervical vertebra showing axis transverse foramen defective.



4



5

but because no reference or data accompanied his claim, it is difficult to determine whether it was mere speculation, or based on concrete evidence.

Age and sex effects. Saunders (1978) found a definite decrease in trait frequency throughout adulthood. This is the pattern expected for a hypostotic (reduced bone growth) trait.

Essentially, it is not clear whether this trait is genetically determined or varies significantly in frequency between populations. In addition, it may be too rare to be of any use in distance analysis.

Scoring protocol. The trait was scored as present if the transverse foramen was not completely closed. In most cases the entire costal process is absent, but on occasion, it is present but not fused to the lateral portion of the transverse process. Manifestation of the trait in this form is easily overlooked. Inter-observer and intra-observer agreement for atlas transverse foramen defective was 0.825 and 0.808 respectively. Inter-observer and intra-observer agreement for the axis transverse foramen defective was 0.586 and 1.0 respectively. In two of the 135 individuals N.S.Ossenberg scored axis transverse foramen defective as present while the author scored it as absent, in two other individuals the author scored the trait as present while N.S.Ossenberg scored it as absent. There were only three individuals for whom both observers scored the trait as present. This explains the low phi correlation coefficient associated with the inter-observer calculation for this trait.

Double transverse foramen of the sixth cervical vertebra

The transverse foramina of C₁ to C₆ transmit the vertebral artery, vertebral veins and small sympathetic nerves, while the transverse foramen of C₇ transmits vertebral veins and small sympathetic nerves. It is common for a transverse foramen in C₃ to C₇ to be divided by a bony bridge or spur (Figure 6). The majority of reports indicate that the sixth cervical vertebra is most often affected (Jackes, 1977; Le Double, 1912; Saunders, 1978; Tulsj, 1975) but Anderson (1963) found C₇ to be most affected. In this study only complete bony bridges observed in the sixth cervical vertebrae were counted as trait present. Again, scoring incomplete bridges as present would introduce an unacceptable amount of inter and intra-observer error.

Etiology. The process leading to the development of this trait remains unknown though Le Double (1912) speculates that it may result from a bony reaction to pressure exerted by the vertebral artery.

Population frequency. The frequency appears to vary between populations, but specific trends are difficult to detect, as it has been common practice to combine complete and incomplete manifestation, and/or report a single frequency of double transverse foramen based on all cervical vertebrae combined. Saunders (1978:262) reported frequencies for complete double foramen of C₆ as ranging from 35% in a male Eskimo-Aleut skeletal sample to 8% in a female Amerind skeletal sample.

Age and sex effects. Further examination of Saunders' (1978) data indicate that the trait is consistently more common in males than in females, though the differences are not always statistically significant. In terms of an age affect, Anderson (1963) observed the trait in

immature as well as adult vertebrae, and Saunders (1978) observed it in vertebrae of fetuses and newborns. To date, no one has conducted a detailed investigation of adult age changes, but because the trait is hyperostotic (excess bone growth), it is expected to increase in frequency with age.

Scoring protocol. Inter and intra-observer agreement are expected to be high when complete double transverse foramina are recorded as present and bony spurs are recorded as absent. In this study intra-observer agreement was perfect and inter-observer agreement was 0.888, also considered high.

Costal foramen of the seventh cervical vertebra

A foramen may occur in the rib element, or costal portion of the transverse process of the seventh cervical vertebrae (Figure 7). The costal portion consists of the anterior root of transverse process, anterior tubercle, costotransverse bar and anterior part of the posterior tubercle (McMinn and Hutchings, 1985:76). Le Double (1912) called this feature a pretransverse foramen. The foramen is distinct from, and can occur in conjunction with, a double transverse foramen. Buikstra (1972) was the first to suggest that the costal foramen is not related to other foramina observed on C₇ and Saunders (1978) also noted differences in accessory foramina types observed on C₇.

Etiology. No information is available on the etiology of this trait.

Population frequency. To date this trait has been relatively neglected. Jackes (1977) reports a frequency of approximately 5% in a Huron ossuary sample.

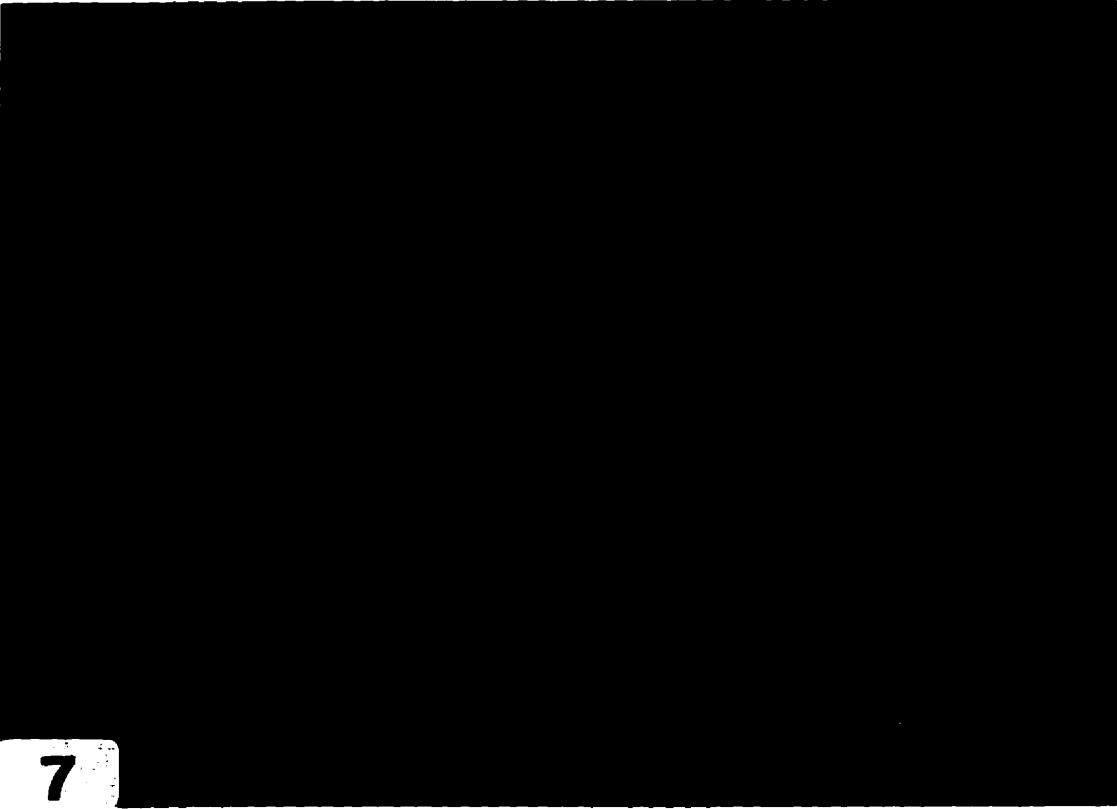
Age and sex effects. No information is available on the effects of age and sex on the frequency of the costal foramen.

FIGURE 6. Superior view of sixth cervical vertebra showing double transverse foramen.

FIGURE 7. Superior view of seventh cervical vertebra showing costal foramen.



6



7

Scoring protocol. In the majority of cases, the manifestation of the costal foramen is easily identified, but it varies in size, and when particularly small, can be difficult to confirm. This problem is exacerbated when the bone in the area is particularly porous or the lighting is poor. Inter-observer agreement was 0.884 and intra-observer agreement was 0.783.

Cervical rib

The seventh cervical vertebra is occasionally associated with a rib, either unilaterally or bilaterally. A cervical rib, as such, is a more defined morphological structure than the normal costal element of the transverse process. It occurs in many forms and is not necessarily symmetrical when occurring on both sides. It ranges in size and shape from a small bony tubercle to what can be considered a “true” rib (comprised of a head, neck and shaft) and can be fused to, or articulated with, the transverse process, and in the latter case, the vertebral body. As a general rule, longer cervical ribs are jointed, while shorter ones are not (Steiner, 1943). The anterior end can be free, connected to the first thoracic rib by a fibrous band, or articulated with, or fused to, the first thoracic rib (Shmorl and Junghanns, 1971). Approximately 50% to 90% of persons with this anomaly remain asymptomatic, while the remainder experience various degrees of pain, sensory and vascular disturbances, or muscular atrophy in the arm and hand as a result of pressure on the brachial plexus, subclavian artery and/or spinal nerves (Epstein, 1976; Honeij, 1920; Kohler and Zimmer, 1968; Shmorl and Junghanns, 1971; Steiner, 1943).

Etiology. Each costal process of the seventh cervical vertebra has its own ossification centre, which appears at approximately the sixth fetal month, and fuses to the vertebral

body between the fifth or six year of life (Barnes, 1994; Epstein, 1976). A cervical rib will be present if fusion does not take place, or the costal process becomes hypertrophied during embryological development (Epstein, 1976). It is important to note that the cervical rib is considered a manifestation of a cranial shift (Barnes, 1994; Kohler and Zimmer, 1968; Merbs, 1974; Shmorl and Junghanns, 1971) and as such would be genetically based.

Population frequency. It is difficult to determine if the frequency of this trait varies between populations. This information is scarce in the literature, probably because the trait is rare. Shmorl and Junghanns (1971) suggest that frequencies vary between 0.5% and 1.0% while Steiner (1943) reports a frequency of 0.0005% and Lanier (1939) reports frequencies of 2.0% and 1.0% for U.S. White and Black males respectively. If the frequencies in the population samples used in this analysis are as low as those reported above, the cervical rib trait may not be useful for distance analysis.

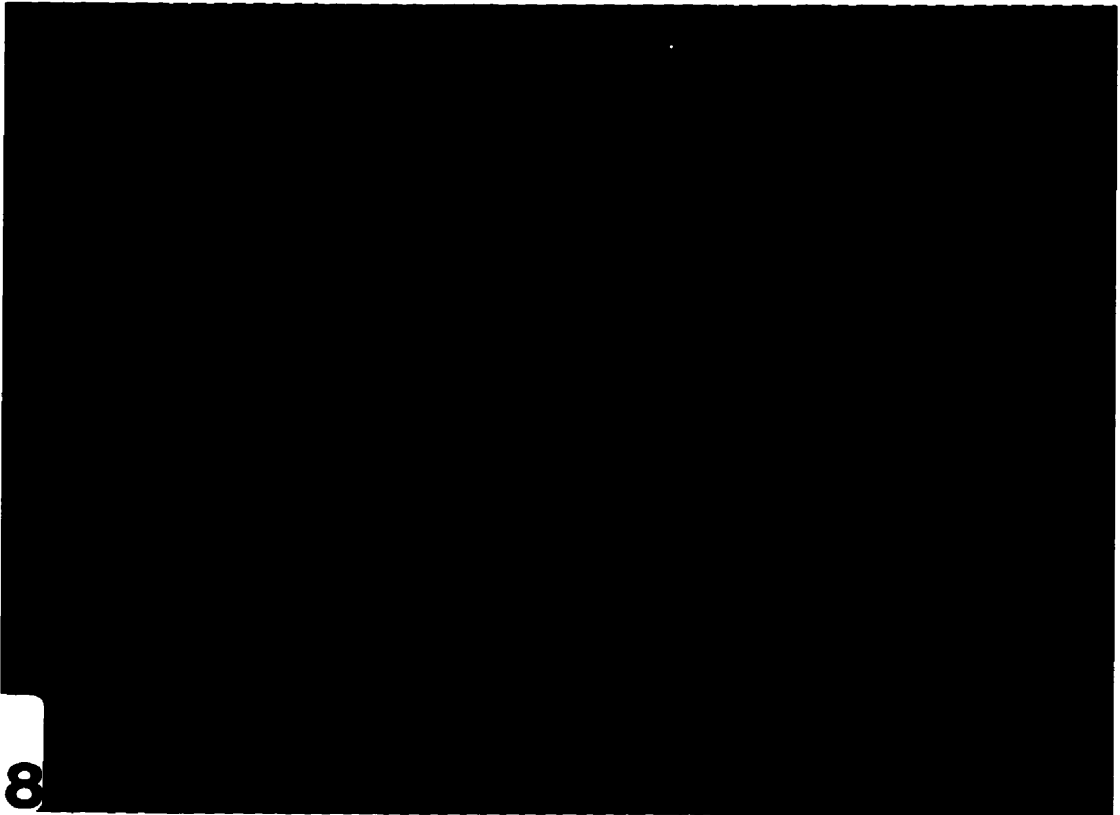
Age and sex effects. Insufficient data are available to determine if the trait is influenced by gender but Honeij (1920) reported it to be more common in males while Steiner (1943) reported it to be more common in females.

Scoring protocol. Mild expression of this trait is manifest as a small, fused tubercle that is curved but does not extend beyond the lateral borders of the transverse processes.

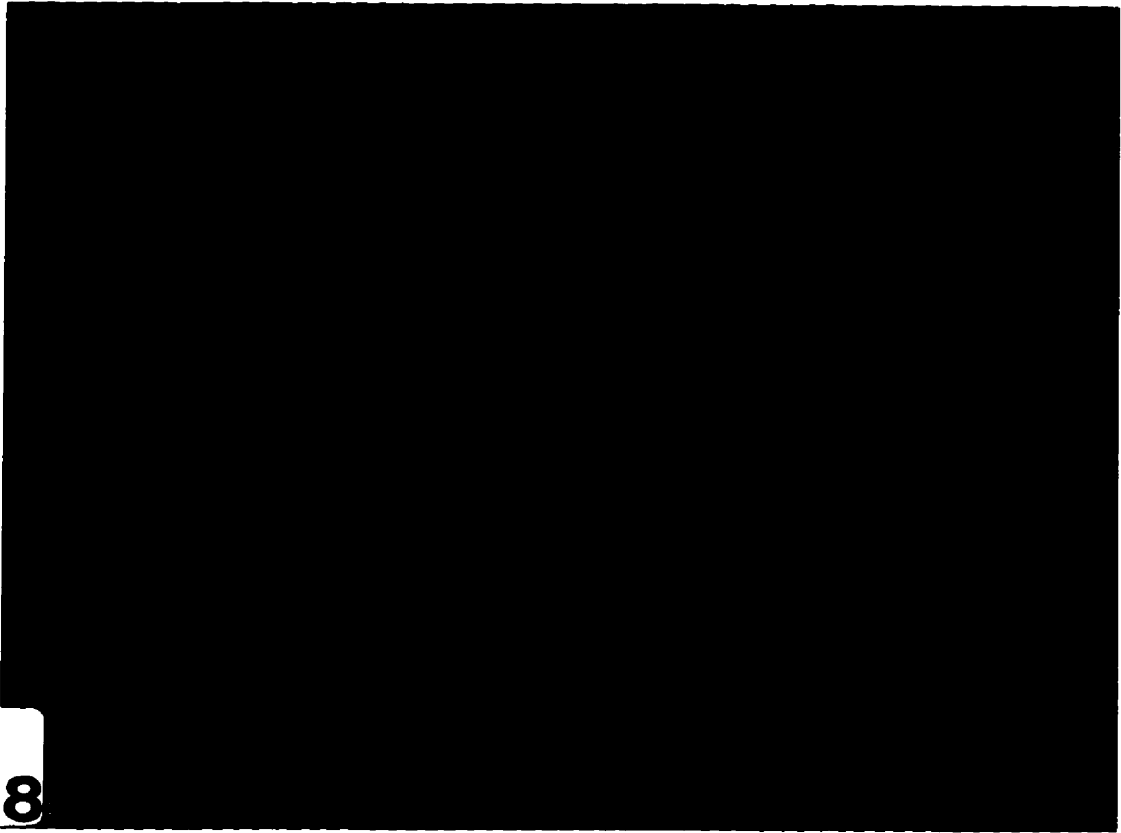
Because it was expected that this form of cervical rib would be difficult to identify with consistency, it was not scored as present (Figures 8a and 8b). Instead, only those cases in which the costal process was clearly elongated, or an articular facet was observed on the body or transverse process of the vertebra, were scored as present. Ambiguous cases

FIGURE 8a. Superior view of seventh cervical vertebra showing articular facet for cervical rib.

FIGURE 8b. Lateral view of same seventh cervical vertebra showing articular facet for cervical rib.



8



8

were scored as absent. Inter and intra-observer agreement for this trait were calculated as 0.995 and 0.987 respectively.

First lumbar vertebra as anticlinal unit

The apophyseal facets of the thoracic vertebrae are oriented coronally while those of the lumbar vertebrae are oriented sagittally. Normally the facets of the twelfth thoracic vertebra are transitional: the superior facets are typically thoracic and the inferior facets are typically lumbar. Known as the anticlinal unit, the vertebra in which the transition occurs varies among individuals. When it occurs in the eleventh thoracic vertebra or higher in the vertebral column, it represents a cranial shift, and when it occurs in the first lumbar vertebra or lower it represents a caudal shift of the thoracolumbar border (Barnes, 1994). In this study the first lumbar vertebra as anticlinal unit was considered as trait present.

Etiology. Though the location of the anticlinal unit is related to, and affects movement of, the vertebral column (Jackes, 1977), the fact that it represents a cranial-caudal shift in axial segmentation suggests that it is genetically based.

Population frequency. There is evidence that the frequency of the L₁ anticlinal unit varies between populations. Stewart (1932) reported a frequency 20% in an Eskimo skeletal sample, Jackes (1977) reported a frequency of 34% in an Huron Indian skeletal sample, and Lanier (1939) reported a frequency of 12% and 9% in a U.S. Black male and U.S. White male skeletal sample respectively.

Age and sex effects. No data are available on the effects of age for this trait. In terms of a sex effect, some data indicate that it is equally distributed (Merbs, 1974), or is more common in females compared to males (Stewart, 1932).

Scoring protocol. This trait was scored as present if either the left, right or both superior facets of the first lumbar vertebra were of the thoracic type and the inferior facets were of the lumbar type. If the anticlinal unit occurred at any other vertebral level the trait was scored as absent.

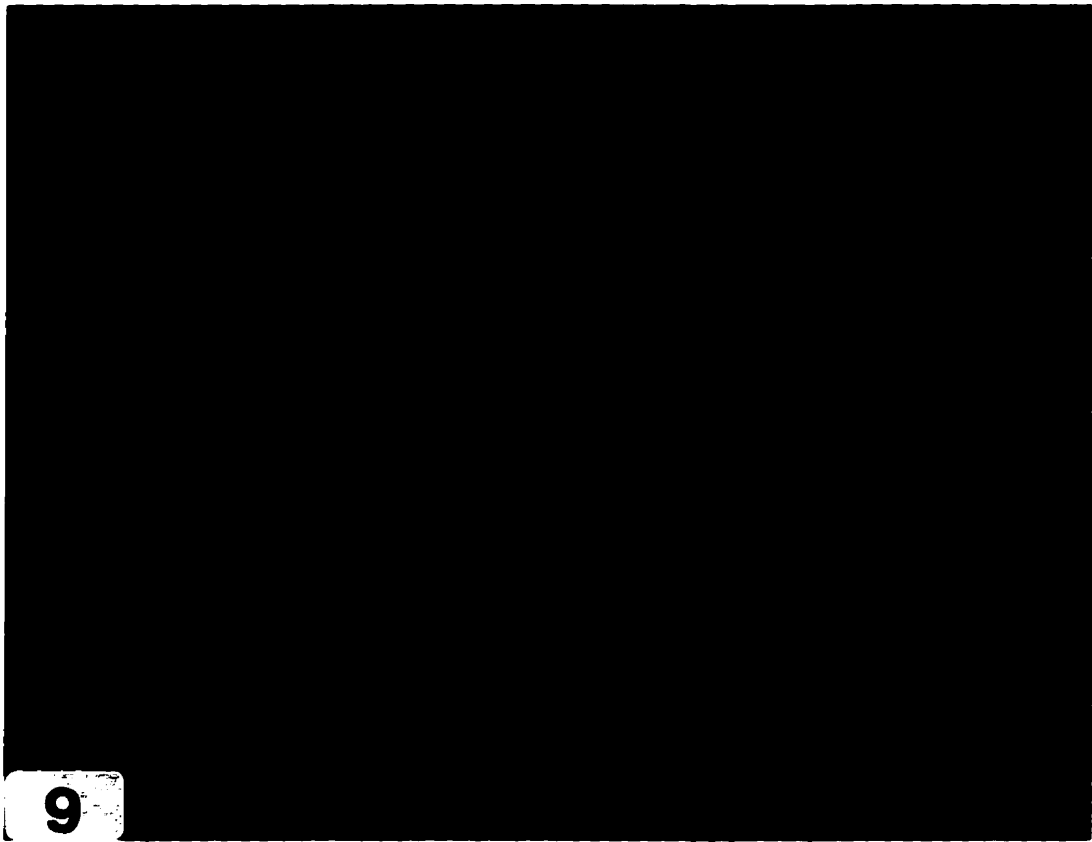
There is some difficulty in scoring this trait consistently as the transition can sometimes occur gradually over more than one vertebra. In addition, it can occur at different levels on the left and right side. In spite of these difficulties, the inter and intra-observer agreement results are high, the phi coefficients calculated as 0.832 and 0.837 respectively.

Lumbar rib

In archaeological skeletal samples a lumbar rib is usually represented by an articular facet, located either on the transverse process or the body of the first lumbar vertebra (Figure 9). They range in size from small tubercle- or wing-shaped bones, to long narrow true ribs. They are usually bilateral in occurrence, though often asymmetrical in morphology.

Etiology. A lumbar rib is formed when the transverse process of the first lumbar vertebra develops from a separate ossification centre and does not fuse to the body (Epstein, 1976). It represents a caudal shift at the thoracolumbar border. The clinical importance of this trait is not clear (Barnes, 1994; Epstein, 1976; Steiner, 1943). ***Population frequency.*** Population frequencies of this variant are difficult to determine from the literature. Lanier

FIGURE 9. Lateral view of first lumbar vertebra showing articular facet for lumbar rib.



(1939:410) reports that it is “almost equally common to negro and white males”, Merbs (1974) reports that caudal shift at the thoracolumbar border (which included first lumbar anticlinal unit in addition to the presence of lumbar ribs) occurs in 40% of Eskimos and 26% of Amerinds while Steiner (1943) reports that lumbar rib occurs in 0.0004% of patients visiting the University of Colorado Medical School and Hospitals. The frequency in Steiner’s sample is probably significantly underestimated because only longer ribs would be detected on radiographs. Another difficulty in determining lumbar rib frequencies from the literature is that the presence of this trait has been used in the past to identify the occurrence of an additional (13th) thoracic vertebra. In other words, any vertebra with associated ribs was considered as thoracic (Stewart, 1932).

Age and sex effects. Saunders (1978) shows that adult age effects vary by population. She found no significant age changes between each adult age group in two Amerind skeletal samples, but did find a significant decrease in frequency between the young and old adult age groups in her Eskimo-Aleut skeletal sample. The effects of gender are not clear: Lumbar ribs may occur equally in males and females (Saunders, 1978), more often in females (Epstein, 1976; Steiner, 1943) or more often in males (Shmorl and Junghanns, 1971).

Scoring protocol. Lumbar rib was scored as present if an articular facet was observed anywhere on the body or transverse process of the first lumbar vertebra.

Because the articular facet varies a great deal in location and size and is easily obliterated by minor bone destruction, lumbar rib is difficult to score consistently, particularly in archaeological skeletal samples. This is reflected in both the inter and intra-

observer agreement phi coefficients which were calculated as 0.741 and 0.800 respectively.

Six unit sacrum

Etiology. The sacrum is normally comprised of five fused vertebrae but a decrease or increase in the total number can occur. Variation in number is established early in embryological development (21 days) when the paraxial mesoderm on each side of the notochord begins segmentation to become somites. Usually five pairs of somites occur in the sacral region but additional (or fewer) can be formed, which lead to the development of additional (or fewer) vertebrae (Barnes, 1994). Early breeding experiments indicate that numerical variations of the vertebral column are hereditary (Lanier, 1939). Additional work in this area indicates that a variation in vertebral number represents a cranial or caudal shift, and thus is genetically based (Kuhne, 1936 in Saunders, 1978). It is important to note that the presence of a six unit sacrum does not always occur at the expense of a vertebra from a contiguous region; i.e. it does not necessarily result from sacralization of the fifth or sixth lumbar vertebra or fusion of the first coccygeal. In other words, six unit sacrum may represent an independent variant. Unfortunately, this trait has been neglected in contrast to the attention paid to the presence of transitional vertebrae at the lumbosacral border.

Population frequency/age and sex effects. Merbs (1974) reported a frequency of 44% in an Eskimo skeletal sample and 26% in a Northwest Coast Amerind skeletal sample, indicating that presence of the six unit sacrum varies significantly between populations. He also noted that the trait occurred in 54% of male and 35 % of female Eskimo

skeletons. This suggests that its development may be partially mediated by size differences. There are no data available on age effects, but because it is manifest at an early stage one would expect it to remain age stable throughout adulthood.

Scoring protocol. Because of the difficulties in identifying the factors that lead to the development of a six unit sacrum (Shmorl and Junghanns, 1971), the decision was made to include all individuals exhibiting the trait in the category of trait present. For individuals with five, four or seven sacral vertebrae the trait was scored as absent.

Inter and intra-observer agreement scores were expected to be high, but were calculated as 0.720 and 0.806 respectively. These values perhaps reflect the difficulty of determining whether or not bony fusion had occurred in specimens with adherent soft tissue.

Lumbarization of the first sacral vertebra

When the first sacral vertebra is “lumbarized”, it takes on characteristics of the lumbar vertebra, and in extreme cases, is detached from the sacrum (Figures 10a, 10b, 11a, and 11b). This is a complex variant, not strictly dichotomous, but rather expressed in stages of increasing severity from barely perceptible signs of lumbarization, to ultimate expression as a unit with no point of bony fusion with the rest of the sacrum. Each element of the first sacral vertebra can be affected and to varying degrees.

The variations include:

- 1) angulation of the body of S_1 to that of S_2 such that a second sacral promontory occurs (distal to the usual L_5 - S_1 promontory) interrupting the normally smooth concavity of the anterior sacral surface;

FIGURE 10a. Anterior view of sacrum showing S₁ lumbarization.

FIGURE 10b. Posterior view of same sacrum showing S₁ lumbarization.

FIGURE 11a. Anterior view of sacrum showing S₁ lumbarization.

FIGURE 11b. Posterior view of same sacrum showing S₁ lumbarization.



- 2) persistence of a disc space between S_1 and S_2 ;
- 3) alae sloping inferiorly from their junction with the S_1 body rather than being horizontal as in the typical sacrum;
- 4) laminar portions of the S_1 vertebral arch separated by a gap from their fused distal homologues;
- 5) inferior articular process elements of S_1 more distinctly developed than normal; though to varying degrees, culminating in morphology consistent with that of fully-developed S_1 - S_2 synovial facet joints;
- 6) the transverse element of S_1 separated from the lateral mass, though in highly variable forms and degrees of expression.

The varying expressions involving the transverse element separation can occur unilaterally or bilaterally, and when present bilaterally, can show markedly asymmetrical degrees of expression. The variations 1) to 6) tend to be expressed cumulatively, such that individuals with weak manifestations might show 1) to 3), those with moderate manifestation would have 1) to 5), while individuals with 6) generally have most of the other characteristics.

Etiology. Lumbarization represents a caudal shift at the lumbosacral border. This is known to be the most common area of the vertebral column in which border shifts occur (Barnes, 1994; Shmorl and Junghanns, 1971). The reason for the shift is not clear but it is suspected to be related to a delay in the formation of the vertebral developmental unit (precursor of the intervertebral disc and adjacent vertebral segment) that borders the

lumbar and sacral regions of the vertebral column. Because different portions of the mesenchymal vertebral column appear and develop at different times, the direction of an existing shift need not be in the same direction as other shifts observed in the associated vertebral column (Barnes, 1994).

With the evolution of bipedality and the concomitant need for an increasingly stable sacrum, the last two lumbar vertebrae became incorporated into the sacrum, i.e. representing a cranial shift (Abitol, 1987; Merbs, 1974; Mitchell, 1934). Despite this evolutionary change, the human vertebral column has tended toward a caudal shift which, if not held in check, can result in the border moving down even further, particularly in the lumbosacral region (Barnes, 1994).

Clinically, an individual with this trait tends to remain asymptomatic throughout life unless the spine is traumatized or subject to a marked increase in stress, such as would result from pregnancy, or a large weight gain over a short period of time (Kohler and Zimmer, 1968). The trait may have a weakening effect on the stability of the articulation between the lumbarized vertebra and the vertebra superior to it (Mitchell, 1934).

Unilateral manifestation of lumbarization is both more common and prone to more clinical problems than bilateral manifestation (Kohler and Zimmer, 1968; Barnes, 1994).

Kuhne's (1932, 1934, 1936) classic work, based on extensive pedigree studies, shows that there is a strong genetic tendency for cranial and caudal shifting (Barnes, 1994).

More recently, experimental work on the rabbit has identified a single gene responsible for a shifting at the lumbosacral border (Sawin et al., 1967).

Population frequency. The pattern of border shifting seems to vary significantly among populations though lumbarization *per se* has not always been investigated in isolation of other border shifts. Because of the difficulties in distinguishing between lumbarization of an S₁ and sacralization of an L₅ (or L₆), some researchers have avoided the problem of distinguishing between them by calling the trait a “transitional vertebra” at the lumbosacral border. Merbs (1974) reports a frequency of lumbarization in 34% and 32% of individuals in an Eskimo and Amerind skeletal sample respectively. Saunders (1978) reports a frequency of lumbosacral transitional vertebrae as 13% in a combined Eskimo-Aleut skeletal sample, and 13% and 1.5% in two distinct Amerind skeletal samples.

Age and sex effects. Saunders (1978) found no significant adult age effects or sex differences in an Eskimo-Aleut or Amerind skeletal sample.

Scoring protocol. Several authors have cautioned against trying to distinguish between lumbarization and sacralization, particularly when the entire vertebral column is not present (Kohler and Zimmer, 1968; Shmorl and Junghanns, 1971). However, because variation in the vertebral column is common, particularly in the lumbar and sacral regions, vertebral number should not be used to identify a transitional vertebra. This is true in any case but especially true with archaeological material. A situation could occur where five regular lumbar, one transitional and five sacral vertebrae are observed in a single individual. Another source of difficulty is that incorporation of the coccygeal vertebra into the sacrum is common, and occurs with increasing frequency with advancing age (Barnes, 1994).

In this study four lumbarization categories are used that ranged from “weak” to “complete” and were originally developed by N.S.Ossenberg based on the features 1) to 6) described above. Prior to final analysis the categories were collapsed into a single category of lumbarization present.

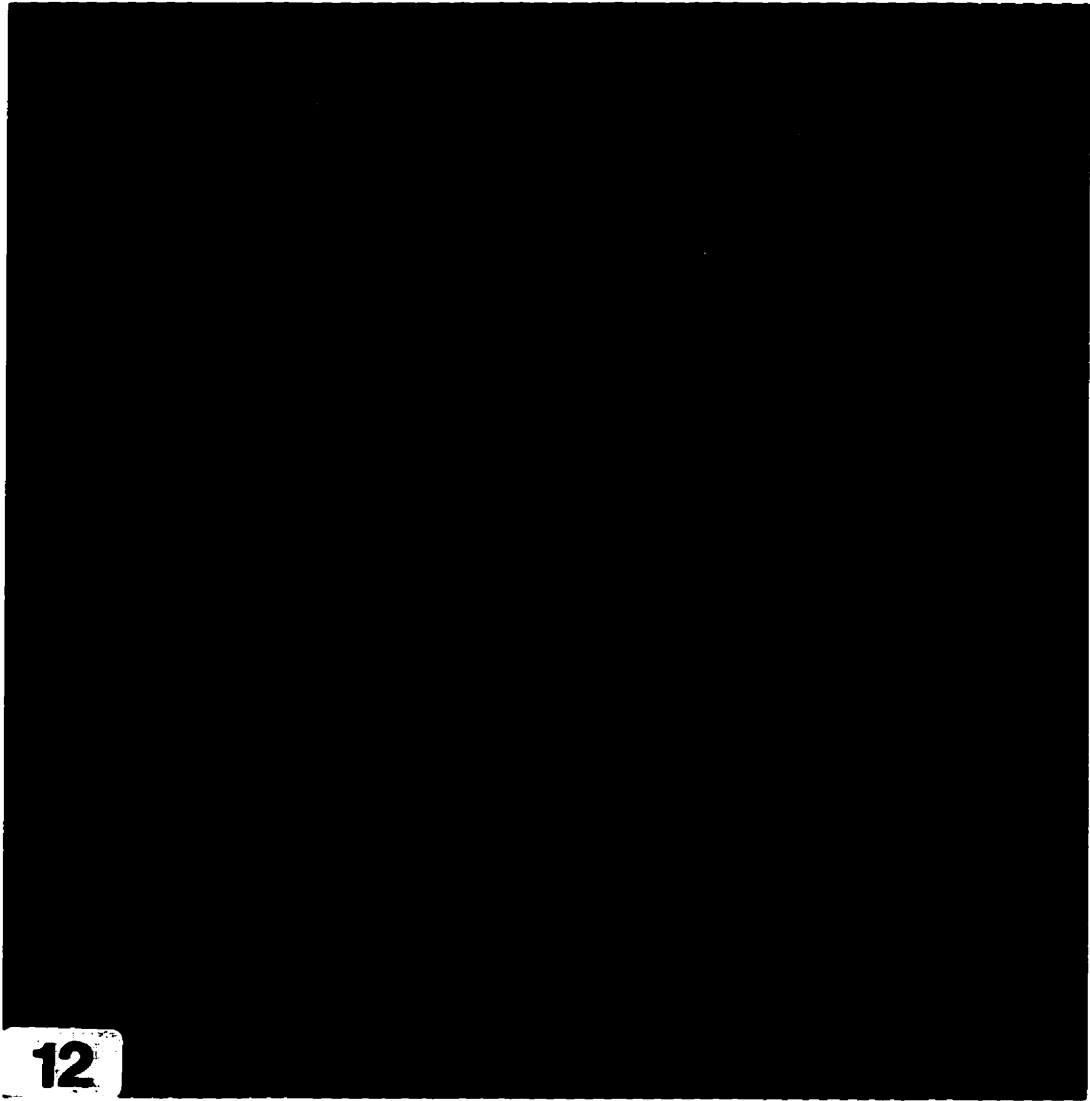
In her scoring protocol prior to 1994, N.S.Ossenberg attempted to distinguish between sacralization and lumbarization, and because of the difficulties associated with that, it was expected that inter-observer agreement level would be low, which it was, 0.432. Intra-observer agreement was 0.759.

Cleft neural arch of the first sacral vertebra

A defect in the neural arch can occur anywhere in the vertebral column but is most common in the first sacral vertebra (Epstein, 1976; Craigmile, 1977; Kohler and Zimmer, 1968; Lorber and Levick, 1967; Saluga, 1988; Shmorl and Junghanns, 1971) (Figure 12). The cleft varies in size from a hairline crack to a fairly wide gap, and is usually symmetrically situated in the median plane. However, if only one side of the arch is affected, the opposite side will grow beyond its boundaries, subsequent to the affected side failing to meet it at the midline (Barnes, 1994; Epstein, 1976; Kohler and Zimmer, 1968). The cleft is filled with tough fibrous tissue which assists the bone in protection of the underlying structures (Barnes, 1994).

In the clinical literature this defect is referred to as *spina bifida occulta* which includes defects ranging from meningeal involvement alone, to the meninges and neural tube in addition to bone. The term “occulta” refers to the fact that in all cases the defect is hidden deep to the skin. Barnes (1994) notes that spina bifida occulta without spinal cord

FIGURE 12. Posterior view of sacrum showing S₁ cleft neural arch.



involvement is a developmental defect of the neural arch (i.e. of the bone), whereas spina bifida occulta with spinal cord involvement is a developmental defect of the neural tube. Though both are genetically based, they represent defects that occur at different stages of development, and ideally, should be treated as distinct traits. Unfortunately, in archaeological material it is almost impossible to distinguish between the two forms (but see Barnes, 1994). Nevertheless, it is probably safe to assume that the majority of defects observed on the first sacral vertebra are related to neural arch, rather than to neural tube, maldevelopment because the former are more common and are clinically insignificant (Barnes, 1994; Craigmile, 1977; James and Lassman, 1962; Saluga, 1988; Shmori and Junghanns, 1971) whereas, within the context of archaeological skeletal samples, individuals with neural tube developmental defects would be unlikely to survive to adulthood (Bradtmiller, 1984).

Etiology. During embryological development, the sclerotome segments surrounding the notochord grow posteriorly to form the precursors of the neural arches. Chondrification of the arches begins at the left and right junctions of the neural arch and vertebral body, and extends posteriorly until, by the third month, the cartilaginous archs unite and surround the spinal cord. Ossification of the neural arches originates from two centres located at the pars interarticularis and, in the sacral region, commences between the fourth and sixth fetal months. As is the case for the development of the sternal aperture, a developmental defect in ossification of the neural arches results from faulty development in the preceding cartilaginous or mesenchymal stage and is genetically based (Barnes, 1994).

Familial studies designed to determine the relationship between spina bifida occulta and spina bifida cystica are difficult to assess because of inconsistencies with the definition of the traits and a lack of comparative methodologies. Asymptomatic parents of offspring with spina bifida cystica, or other forms of neural tube defects, were shown to have a higher frequency of spina bifida occulta than the general population (Gardner et al., 1974; Lorber and Levick, 1967). On the other hand, Laurence and colleagues (1968) found a relationship between spina bifida occulta with neural tube defects and spina bifida cystica, but not between spina bifida occulta with neural arch defects only. Again, Barnes (1994) cautions that the two forms of spina bifida occulta result from developmental defects occurring in different tissues. This does not necessarily exclude the possibility that the same set of genes contributes to both types of defects. Further assessment of the relationship between these disorders is required.

Population frequency. In terms of geographical distribution, there is definitely variation in the frequency of congenital malformations in general and neural tube defects in particular (Craigmile, 1977; Leck, 1984; Post, 1966), but whether or not this is the case for spina bifida occulta without neural tube defects, is not clear. If these defects are genetically related then frequency differences between geographical populations are expected.

Age and sex effects. Because of the difficulty with the definition of “spina bifida” in the clinical literature, it is not clear if, and to what extent, age and sex are factors in trait expression.

Scoring protocol. In any individual where the two halves of the neural arch of the first sacral vertebra had not fused, the trait was scored as present. As previously discussed,

this can be manifest as a small or large cleft in the midsagittal plane, or offset to the left or right, or can have one side overlapping or “riding up” over the other whereby the cleft is oblique in orientation. In cases where the second vertebra was also affected, the trait was scored as present. However, if the entire sacral canal was open the feature was scored as unobservable, because the latter is more likely to represent a severe form of spina bifida.

Manifestation of neural arch defect of the first sacral vertebra is usually clear except in cases where the two arches had met in the midline but not coalesced. Inter and intra-observer error for this trait had phi coefficients calculated as 0.868 and 0.852 respectively.

High sacral hiatus

The sacral hiatus is defined as the inferior opening of the sacral canal. It normally occurs at the level of the fourth vertebra (Trotter and Letterman, 1944) or lower, but location can vary considerably among individuals (Anderson, 1963; Barnes, 1994; Trotter and Letterman, 1944).

Etiology. Factors that determine the most distal extent of fusion of left and right laminae are not well understood. Development of the trait may be related to chondrification of the neural arches of the sacrum.

Population frequency. Trotter and Letterman (1944) report the hiatus to be above the fourth vertebra in 45% and below in 20% of individuals from a skeletal sample of U.S. Whites and Blacks. Stewart (1932) reports it to occur at or above the level of the third foramen in 13% of individuals in an Eskimo skeletal sample.

Age and sex effects. No information is available on the effects of age and sex on the frequency of high sacral hiatus.

Scoring protocol. High sacral hiatus was counted as trait present when it was situated at or above the level of the third sacral vertebra. In cases where a complete sacral spina bifida was present, sacral hiatus level was scored as unobservable.

There is some ambiguity in recording this trait because identifying the level of the hiatus depends somewhat on the angle at which the sacrum is viewed and is a somewhat subjective assessment. Nevertheless, inter and intra-observer agreement of 0.868 and 0.799 respectively were higher than expected and considered acceptable.

CHAPTER III: STATISTICAL METHODS

Descriptive Statistics

Summary statistics pertaining to numbers of observations with trait present, total number of observations and corresponding percentage frequencies by population group, sex and age group were tabulated for each of the 14 traits.

Logit Modeling

Categorical data analysis, applicable to variables in the form of categories, presents the researcher with particular challenges that are not encountered in the analysis of continuous variables. Categorical variables such as trait presence/absence are not amenable to the numerous well developed and widely used statistical techniques, such as analysis of variance and regression analysis. Recently, with the increasing availability and use of computer technology as a tool in statistical analysis, several advances have been made within the field of categorical data analysis. The development of logit modeling is one example. Logit modeling is used in this study to determine in what way, and to what extent, the variables population group, age and sex affect the presence of non-metric traits of the vertebral column. Logit models can be developed in two different ways: directly, as a natural description of binary response variables, or as a by-product of loglinear models which are applicable to data in the form of multiway frequency tables. A common feature of both logit and loglinear models is the "odds ratio", a statistic used to describe the association between two categorical variables.

To understand the theoretical underpinnings of logit modeling some knowledge of odds ratio and loglinear analyses is required. The following two sections will serve as an introduction of these techniques. This will be followed by an introduction of logit modeling and a discussion of its specific application in the present study. Finally, the stepwise procedures used to identify the most appropriate or “best” model will be summarized.

Odds ratio

The odds ratio is a measure of association between two categorical variables. Consider the following example of a 2-by-2 contingency table containing the frequencies of cross-classifications of the two categorical variables, “Trait Present” and “Population”.

		Population	
		A	B
Trait Present	Yes	20	10
	No	92	86

The odds of having the trait present are 20/92 or .22 to 1 in population A and 10/86 or .12 to 1 in population B. From this information one can calculate the ratio of the two odds: $.22/.12 = 1.8$. An individual in population A is almost twice as likely to exhibit the trait as an individual in population B. If the odds of having the trait were the same in both populations their odds ratio would equal 1. An odds ratio of 1 indicates statistical independence of the variables Population and Trait Present, which can also be determined from the chi-square test of independence. An advantage of the odds ratio over the chi-

square test is that the former also indicates the degree of association between the two variables: the further the odds ratio is from 1, the greater the association.

The odds ratio measures negative and positive associations on different scales, the former on the interval 0 to 1 and the latter on the interval 1 to infinity. Variables from two different contingency tables, which exhibit the same level of association but in opposite directions, will have odds ratios which are reciprocals of one another.

A simplified measure is obtained by calculating the logarithm of the odds ratio. In terms of this measure, tables with equal association but in opposite directions, have log odds ratios which are the negative of one another; negative associations lie between negative infinity and zero while positive associations lie between zero and infinity with zero representing statistical independence. From the following table, where π represents the population probability of being in one of each of the four cells,

		Variable A	
		A ₁	A ₂
Variable B	B ₁	π_{11}	π_{12}
	B ₂	π_{21}	π_{22}

$$\text{odds ratio} = \theta = \left(\frac{\pi_{11}\pi_{22}}{\pi_{12}\pi_{21}} \right)$$

$$\log \theta = \log \left(\frac{\pi_{11}\pi_{22}}{\pi_{12}\pi_{21}} \right)$$

$$= \log \pi_{11} + \log \pi_{22} - \log \pi_{12} - \log \pi_{21}$$

An estimate of the odds ratio, or log odds ratio, can be determined by replacing the unknown population probabilities (π) with sample frequencies (n) or proportions (p):

$$\hat{\theta} = \left(\frac{p_{11}p_{22}}{p_{12}p_{21}} \right) = \left(\frac{n_{11}n_{22}}{n_{12}n_{21}} \right)$$

$$\log \hat{\theta} = \log p_{11} + \log p_{22} - \log p_{12} - \log p_{21} = \log n_{11} + \log n_{22} - \log n_{12} - \log n_{21}$$

An approximate standard error for the log odds ratio of a given 2-by-2 table can easily be calculated

$$SE_{\log \hat{\theta}} = \sqrt{\frac{1}{n_{11}} + \frac{1}{n_{22}} + \frac{1}{n_{12}} + \frac{1}{n_{21}}}$$

Thus, an approximate 95% confidence interval for the sample log odds ratio is given by

$\log \hat{\theta} \pm (1.96)SE_{\log \hat{\theta}}$. An approximate 95% confidence interval for the true (population) odds ratio follows easily as the interval with lower and upper endpoints:

$$\text{antilog} [\log \hat{\theta} - (1.96)SE_{\log \hat{\theta}}] \text{ and } \text{antilog} [\log \hat{\theta} + (1.96)SE_{\log \hat{\theta}}].$$

Note that 1.96 is the 97.5th percentile of the standard normal distribution.

This method of measuring association has three properties that are advantageous to the present study. Firstly, the odds ratio can be used to make specific statements about the data. From the table on page 91, one can say that an individual in population A is almost twice as likely to have the trait present as an individual in population B. Secondly unlike phi and Pearson's chi-squared, the odds ratio is unaffected by scaling of rows or columns. Specifically, extreme range in values among the marginal totals will not decrease the magnitude of the measure. In addition, it can be used to compare relationships between variables across numerous multidimensional tables. Finally, odds ratios occur naturally in loglinear and logit models and thus provide an effective interpretation of the results of this type of analysis.

It should be noted that odds ratios can be used to calculate association in three-way and higher dimension tables, and that the variables need not be binary. An I -by- J table contains subsets of 2-by-2 tables and odds ratios can be calculated for each subset. This allows the researcher to “isolate” different parts of the table, and thus investigate, various subhypotheses of specific interest.

From Reynolds (1977:43), let P_{ij} denote the proportion of observations in the ij th cell of an I -by- J table. A basic set of odds ratios is then

$$\hat{\theta}_{ij} = \left(\frac{P_{ij}P_{IJ}}{P_{Ij}P_{ij}} \right) \quad i=1,2,\dots,I-1; \quad j=1,2,\dots,J-1.$$

In this example the bottom right cell of the table is the reference point. This is consistent with the “corner-point” constraints used in the logit analysis (defined later).

Loglinear analysis

The goal of loglinear analysis is to “build” a model that accounts for the pattern of data distribution observed in a multidimensional contingency table. The modeling process focuses on relationships among response variables (Agresti, 1996:166), and like other statistical techniques, attempts to explain variation in the data. The unit of analysis is the cell frequency. The method consists of exploring a family of ANOVA-like models for the *logarithm* of the expected cell frequency.

Loglinear modeling is similar to chi-square analysis in that expected cell frequencies are compared with observed cell frequencies. The latter provides a test of independence between the two variables: under the assumption of independence the data would be distributed in a specified way. This pattern of distribution, expressed by the

expected frequencies, is compared to the observed frequencies. With odds ratio analysis independence would result in an odds ratio of 1 and a log odds ratio of 0. Loglinear analysis is more detailed than the chi-square test of independence because it deals simultaneously with several categorical variables and interactions among these variables. The method proposes and tests, in a step-wise manner, various models. Choice of the best model is usually determined from either of the two following procedures:

1) *Forward selection*. The base model contains a single term for each variable.

Interaction terms are added separately to the base model and the term that gives the greatest improvement in fit is added to give the new model. The process continues until the best model is identified.

2) *Backward elimination*. The most complex, or saturated model is chosen as the base model and terms are removed successively, the one having the least effect on the goodness of fit being removed first. The simplified version becomes the new model and the process continues until the best model is identified.

Note that in the backward elimination (forward selection) procedure, once a term is removed (added) it is no longer a candidate in the cycle (Bishop, Fienberg and Holland, 1975:165-166). For both *forward selection* and *backward elimination*, choosing the best model to represent the data involves a comparison of observed cell values and estimated expected cell values, the latter of which are based on the proposed model.

It should be noted that there is a practical reason why the logarithms of expected cell frequencies are used to build models. Though it is beyond the scope of this work to review in detail the properties of logarithms, note that if $A=(B)(C)$ then $\log(A) = \log(B) + \log(C)$;

that is, logarithms convert multiplication to addition. Associations between categorical variables in a multidimensional contingency table are expressed by multiplicative relationships among cell probabilities or, equivalently, cell frequencies. Using logarithms the relationships are converted to additive (ANOVA-like) models for cell log-expected frequencies in terms of parameters for main effects and interactions of the variables in the table.

The following is an examination of the potential models that could account for data observed in a two-way, 2-by-2 contingency table. Let $\lambda_{ij} = \log(\eta_{ij})$ and η_{ij} = expected frequency of a cell in the i th column and j th row under the proposed model, and let the row and column variables be denoted as A and B respectively. Though the choice of parameter constraints is arbitrary, the SAS GENMOD procedure (SAS System for Windows, version 6.10, 1993) sets the parameter for the last level of each variable equal to zero, the so-called “corner-point” constraints. As will be shown, this allows parameter estimates to be directly converted to odds ratios (Agresti, 1996:149).

- 1) *No Effects Model.* If there are no row or column effects then the logarithms of the expected frequencies in each cell will equal a constant. Written mathematically, the no effects model is $\lambda_{ij} = \mu$. The parameter μ is defined by the corner-point constraint such that $\mu = \lambda_{11}$. The no effects model indicates that all cells of the table are equi-probable, and as a consequence, that the categories of both variables are equi-probable and there is no association between the two variables. In a 2-by-2 contingency table, the probability of being in a given cell is 0.25 and the variables A and B are statistically independent.

2) *Model Containing Only Row Effects.* This model would be written mathematically as

$\lambda_{ij} = \mu + \mu_i^A$. The term μ_i^A denotes the i th effect of variable A. In this model, the levels of the row variable A are not equally probable, and μ_i^A reflects the amount that the i th level of A differs from the reference value (λ_{11}). The value of μ_i^A is given by $\mu_i^A = \lambda_{i1} - \lambda_{11}$. Regardless of the size of the table, the row effects can be considered as a set of parameters, one for each level of the row variable. The row-effects-only model asserts that the levels of the column variable are equally probable, the levels of the row variable are not, and the two variables are statistically independent.

3) *Model Containing Only Column Effects.* $\lambda_{ij} = \mu + \mu_j^B$, with

$\mu_j^B = \lambda_{1j} - \lambda_{11}$ (analogous to previous case).

4) *Model Containing Row and Column Effects.* Mathematically, this model is written as

$\lambda_{ij} = \mu + \mu_i^A + \mu_j^B$ where the terms μ_i^A and μ_j^B are as above. This is the *independence* model and is analogous to the underlying model on which the chi-square test of independence is based. The model states that the distribution of variable A and variable B are not equal across all categories and, most importantly, that A and B are statistically independent. It is easily seen that the log odds ratio, $\lambda_{11} + \lambda_{22} - \lambda_{12} - \lambda_{21}$, equals zero, i.e. the odds ratio equals 1, indicating no association between the variables.

The independence model can be considered the most basic or simplest loglinear model of interest. The first three models described do not include all of the main effects (row, column and higher dimensions effects) and very rarely represent reality.

Such models usually apply to a very restricted set of problems since they impose equal probabilities for categories of variables whose terms do not appear in the model (Colgan and Smith, 1978:153).

5) *Interaction Model*. This model is identical to the previous one except for the addition of a two-factor interaction term that measures the association between A and B. It is written as $\lambda_{ij} = \mu + \mu_i^A + \mu_j^B + \mu_{ij}^{AB}$. The value of μ_{ij}^{AB} is given by

$\mu_{ij}^{AB} = \lambda_{ij} + \lambda_{11} - \lambda_{1j} - \lambda_{i1}$, and as such, is a log odds ratio. This is referred to as the “saturated model” because there are as many parameters as cells in the table.

About the independence model (#4 above) Agresti (1996:151) states “When variables are chosen wisely for a study, this model is rarely appropriate” (Agresti, 1996:151). That is, most loglinear models will contain at least one interaction term.

The above ideas generalize to 3-way and higher dimensional tables. The saturated model for a 3-way table is $\lambda_{ijk} = \mu + \mu_i^A + \mu_j^B + \mu_k^C + \mu_{ij}^{AB} + \mu_{ik}^{AC} + \mu_{jk}^{BC} + \mu_{ijk}^{ABC}$ with $\mu_1^A = \mu_1^B = \mu_1^C = \mu_{1j}^{AB} = \mu_{i1}^{AC} = \dots = \mu_{111}^{ABC} = 0$.

Hierarchical submodels are obtained by eliminating specific interaction terms and their lower-order relatives. It is important to note that loglinear modeling is governed by the hierarchy principle. The hierarchy principle states that any model containing an interaction term must also contain all main effects and lower order interactions that are included in that interaction term. Though it is possible (but mathematically difficult) to produce a nonhierarchical model, the hierarchy principle allows for an orderly and easily interpreted method of building loglinear models.

As noted above, the GENMOD procedure (SAS System for Windows, version 6.10, 1993) sets the parameter value for the last level of each variable equal to zero. Using corner-point constraints thus defined, the White population group, old adult age cohort and female gender group, are set to zero and every loglinear two-way interaction parameter, μ_{ij}^{AB} , μ_{ik}^{AC} , μ_{jk}^{BC} , is a *log odds ratio* for the cells at the 4 corners of a subset table. For the μ_{ij}^{AB} interaction term, $\mu_{ij}^{AB} = \lambda_{ijkl} + \lambda_{ljkil} - \lambda_{ijlki} - \lambda_{iljkl}$. (Note that each λ term represents one of the four corners of a 2-by-2 subtable for variables A and B). Thus, log odds ratios follow directly from loglinear parameter estimates (Agresti, 1996:149 and 160).

Logit analysis

Though logit models can be derived directly from multidimensional contingency tables, for the sake of simplicity logit modeling will be considered within the context of its relationship to loglinear modeling. Logit modeling is used when there is specific interest in the effects of explanatory (independent) variables on a single, binary response (dependent) variable. While the quantity modeled in loglinear analysis is the log of the expected cell frequency, in logit modeling it is the log odds of the response variable. The goal is to build a model for the log odds ratios that accounts for the observed variation in the cell frequencies. Logit modeling is used in this study to determine if, and to what extent, the explanatory variables of population group, age and sex affect the odds of trait presence versus absence.

To illustrate the relationship between loglinear and logit models, consider the following loglinear model that has been fitted to a set of data containing variables for trait (present or absent), age and sex, denoted by A, B, and C respectively:

$$\text{Let } \lambda_{ijk} = \mu + \mu_i^A + \mu_j^B + \mu_k^C + \mu_{ij}^{AB} + \mu_{ik}^{AC} + \mu_{jk}^{BC}.$$

Suppose A is a binary response variable with A=1 representing trait present and A=2 representing trait absent, and B and C are explanatory variables, then the logit model for the odds of trait present versus absent would be expressed mathematically as $\text{logit}_{jk} =$

$$\log\left(\frac{\eta_{1,jk}}{\eta_{2,jk}}\right). \text{ Because of the additive nature of logarithms, } \log\left(\frac{\eta_{1,jk}}{\eta_{2,jk}}\right) = \lambda_{1,jk} - \lambda_{2,jk}.$$

Substituting the appropriate loglinear model formulas, we get:

$$\begin{aligned} \text{logit}_{jk} &= (\mu + \mu_1^A + \mu_j^B + \mu_k^C + \mu_{1j}^{AB} + \mu_{1k}^{AC} + \mu_{jk}^{BC}) - (\mu + \mu_2^A + \mu_j^B + \mu_k^C + \mu_{2j}^{AB} + \mu_{2k}^{AC} + \mu_{jk}^{BC}) \\ &= (\mu_1^A - \mu_2^A) + (\mu_{1j}^{AB} - \mu_{2j}^{AB}) + (\mu_{1k}^{AC} - \mu_{2k}^{AC}) \end{aligned}$$

In applying cornerpoint constraints with the parameter for the first level of each variable set to zero, $\mu_1^A = \mu_{1j}^{AB} = \mu_{1k}^{AC} = 0$, $\text{logit}_{jk} = \mu_2^A + \mu_{2j}^{AB} + \mu_{2k}^{AC}$. Substituting β for μ_2^A , β_j^B for μ_{2j}^{AB} , and β_k^C for μ_{2k}^{AC} , $\text{logit}_{jk} = \beta + \beta_j^B + \beta_k^C$. Thus, the log odds of (trait present/trait absent) depends on a constant term β , plus main effects for B (age) and C (sex). The following table compares loglinear and logit models.

Loglinear model for $\lambda_{ijk} = \log(\eta_{ijk})$	Logit model for $\text{logit}_{jk} = \log\left(\frac{\eta_{1jk}}{\eta_{2jk}}\right)$
$\mu + \mu_i^A + \mu_j^B + \mu_k^C + \mu_{jk}^{BC}$	No effects: β
$\mu + \mu_i^A + \mu_j^B + \mu_k^C + \mu_{ij}^{AB} + \mu_{jk}^{BC}$	One main effect: $\beta + \beta_j^B$
$\mu + \mu_i^A + \mu_j^B + \mu_k^C + \mu_{ij}^{AB} + \mu_{ik}^{AC} + \mu_{jk}^{BC}$	Two main effects: $\beta + \beta_j^B + \beta_k^C$
$\mu + \mu_i^A + \mu_j^B + \mu_k^C + \mu_{ij}^{AB} + \mu_{ik}^{AC} + \mu_{jk}^{BC} + \mu_{ijk}^{ABC}$	One two-way interaction: $\beta + \beta_j^B + \beta_k^C + \beta_{jk}^{BC}$

Another advantage of logit modeling is that the parameter estimates for main effects of the explanatory variables represent log odds ratios between the response variable and the associated explanatory variable. If the data in a 2-by-2 table are represented by the “one main effect” logit model illustrated in the above table, the difference $\beta_1^B - \beta_2^B$ is the log odds ratio of B with A (the response variable). It follows that because cornerpoint parameter constraints set the first level of each variable to zero, $\beta_1^B = 0$; therefore β_2^B is the log odds ratio of B with A. One need only calculate the antilog of this parameter estimate to determine the odds ratio.

In this study the odds ratios for the population group variable will contain the odds of trait present to trait absent of the White group in the denominator. The odds ratio for the

sex variable will contain the odds of trait present to trait absent of the female gender in the denominator. The odds ratio for the age variable will contain the odds of trait present to trait absent of the old adult cohort in the denominator.

Building the Logit Model

As the number of variables in a cross-classification table increases, the number of potential models increases as well. It is not practical or realistic to randomly propose and test models. Instead, it is more efficient and (for reasons discussed below) statistically necessary to proceed in a stepwise manner. Though there is more than one direction in which this can be done, e.g., *forward selection* versus *backward elimination*, the former approach will be used in this study.

The goodness-of-fit test statistic used to compare the estimated expected frequencies with the observed frequencies is the G^2 or likelihood ratio chi-square statistic (Agresti, 1996:29). It is defined as:

$$G^2 = 2 \sum (\text{observed}) \log \left(\frac{\text{observed}}{\text{expected}} \right)$$

The G^2 statistic is asymptotically equivalent to the Pearson chi-square statistic, and provided the sample size is adequate, follows the χ^2 distribution. Degrees of freedom are calculated as the total number of cells in the table minus the total number of parameters in the model. An important property of the G^2 statistic is that it can be partitioned into additive components. As a result, further information about the contribution of an individual term, given the presence of all the other terms, can be examined for statistical significance. This is done by calculating the difference of the G^2 's for the two models that

differ only by the term in question (Colgan and Smith, 1978:157). Like the G^2 statistic, the delta G^2 follows the χ^2 distribution. If the additional term is statistically significant it means that the expected frequencies associated with the latter model are significantly different than the expected frequencies associated with the former model. Thus, the additional term must be included in the final model. In summary, as terms are added their contribution to the model can be assessed independently.

The *forward selection* approach begins with the most basic model which increases in complexity as terms are added. This procedure was carried out in GENMOD, SAS System for Windows, version 6.10 (1993) and is outlined below. The White, old adult, female group was chosen as the “corner-point” reference group.

- 1) Both G^2 and its associated significance probability (P) for the *No Effects Model* are determined and examined for significance. Because of the simplicity of this model (it states that the log odds of trait presence is the same for all cells in the 3-way table of population group-by-age-by-sex), it is not surprising that the expected and observed values differ significantly.
- 2) The population group variable is added to the previous model. The new G^2 and P values indicate to what extent the expected frequencies based on the new model (which includes the constant term from the *No Effects Model* in addition to the term for population group effect) differ from the observed frequencies. The difference of G^2 statistics between the No Effects Model and the model including an effect for population group is calculated by subtracting the G^2 and degrees of freedom of the

latter from the former. If delta G^2 is significant, this indicates that the new term, population group, is statistically significant.

The same procedure is carried out for both the age and sex variables.

- 3) Of the three new single-effect models that are created with the population group, age and sex variables, the variable that contributes most significantly to the model, in other words the one with the smallest P value, becomes the model to which the two remaining terms will be added. The procedure is essentially the same as in the previous step. If the population group term was most significant, the age and sex terms will be added to the population group effect model separately to create two new models. If the difference between the G^2 of the population group effects and population group plus age effects model is significant, then the age variable should be included in the model. If both age and sex effects are significant then the more significant of the two will be included in the new model, and the less significant term added, in the next step, to this model.

This procedure continues until no additional terms are statistically significant.

Following the choice of the best model, parameter estimates and antilogarithms of parameter estimates (i.e. log odds ratios and odds ratios) associated with this model are produced.

Model Diagnosis

In addition to the probability values associated with the G^2 of each model and delta G^2 of each added term, adjusted residuals are also used to determine and assess the fit of the “best” logit model. While the former can be considered as a broad summary of how well

the model fits the data, the latter provide more detailed insight into the fit of the data, on a cell-by-cell basis. Adjusted residuals were calculated for each cell in the multidimension table based on the following formula:

$$d_{ij} = \frac{e_{ij}}{v_{ij}} \quad \text{where } e_{ij} = \left(\frac{n_{ij} - \eta_{ij}}{\eta_{ij}} \right) \text{ and } n_{ij} \text{ and } \eta_{ij} \text{ are the observed and expected}$$

frequencies respectively in the i th column and j th row the of table and v_{ij} is its estimated standard error (Agresti, 1996:91). Provided a sufficiently large sample size, each adjusted residual will be approximately distributed as a standard normal variable (i.e. a normally distributed variable with mean equal to zero and variance equal to 1.0). Adjusted residuals less than -1.96 or greater than 1.96 (i.e. those that fall within two standard deviations of the mean) indicate a significant discrepancy between the observed and expected frequencies in those cells, and serve to identify where the fit of the model is weakened. Though a certain model may appear to fit the data better than the subsequent more complex model in the sequence, an examination of the adjusted residuals will sometimes indicate that the latter has fewer statistically significant adjusted residuals. In this case, the latter would be chosen as the best model to represent the data.

Once the final model is chosen the adjusted residuals are used to assess its fit. If several are statistically significant, it is often possible to decipher a pattern of deviance; i.e. is the deviance associated with a specific population group, age or sex? When compared with the frequency data of the subsamples in question, additional insight may be obtained.

In addition, lower and upper confidence intervals of the odds ratios are calculated.

The SAS System for Windows, version 6.10 (1993) produces standard errors for each of

the parameters in the final logit model. Confidence intervals associated with each odds ratio provide information regarding the range of values of all odds ratios associated with each comparison.

Inter-Trait Association¹

In addition to the effects of the variables population group, age and sex on the expression of trait presence/trait absence, inter-trait association is also of interest. Determination of the existence of association between traits, both cranial and post-cranial, has traditionally been investigated with the X^2 test of independence. The X^2 test statistic does not provide information regarding the strength of association between two traits, instead it simply indicates that the traits are or are not statistically independent. The phi coefficient is used in this study because it specifically measures the amount of association between two traits, on a -1 to +1 scale, with zero indicating no association, and -1 and 1 indicating perfect association. The phi coefficient is the categorical data equivalent of the Pearson product-moment correlation coefficient which was developed for quantitative data.

Briefly, the phi coefficient measures the extent of association between two binary variables, in this case two non-metric traits of the vertebral column. Phi is expressed as a correlation coefficient and is calculated from a 2-by-2 contingency table arranged as follows:

¹ Statisticians reserve the word “correlation” for continuous variables and “association” for discontinuous variables.

		Variable A	
		A ₁	A ₂
Variable B	B ₁	n ₁₁	n ₁₂
	B ₂	n ₂₁	n ₂₂

The formula for calculating the phi coefficient is expressed as:

$$\hat{\phi} = \frac{n_{11}n_{22} - n_{12}n_{21}}{\sqrt{n_{1+}n_{2+}n_{+1}n_{+2}}}$$

Phi ranges from -1 to +1 with zero indicating no association between variable A and variable B. Because the phi coefficient is proportional to X^2 , the Pearson chi-square statistic, $X^2 = n_{++}\hat{\phi}^2$, the X^2 test statistic can be used to test $H_0: \phi = 0$. This test will indicate whether the observed association is due to a real relationship between the scorings or due to chance. If the sample size is small, the significance of the phi coefficient is determined using Fisher's exact test (Siegel and Castellan, 1988:233).

Associations among traits are of interest within the context of their morphological significance and etiology. Accordingly, the results of the phi coefficient analysis were examined in an attempt to discern *patterns* of relationships among traits. In addition, a matrix of the phi coefficients was used, in lieu of a correlation matrix, in the Mahalanobis distance formula. Information pertaining to, and justification for, use of the phi coefficient in the distance formula appears in the following section, Distance Analysis.

The SAS System for Windows, version 6.10 (1993) was used to calculate phi coefficients, X^2 and Fisher's exact test when sample sizes were small. The pooling of all

data (by population group, age, and sex) for each trait resulted in a total of 72 tests of association.

Distance Analysis

Previously, probit analysis has been used to model the probability of trait presence against the variables age, sex and skeletal deformation (Konigsberg, et al., 1993). Probit analysis was originally introduced for models in toxicology in which the relationship between a specified dose of a chemical (e.g., a pesticide) and a quantal response (all-or-nothing; e.g., survival versus death) was measured (Agresti, 1996:79-80; Bishop, Feinberg and Holland, 1975:367). The analogy of the “dosage threshold” model with the quasi-continuous threshold model proposed for the expression of non-metric traits, in which the traits are the discontinuous morphological expression of an underlying continuously distributed trait “liability” (Saunders, 1989), is obvious. In addition, the probability distribution associated with the probit values is a standard normal curve, the same curve that is assumed to represent the probability of trait liability. Konigsberg and colleagues (1993) inserted “threshold values”, or probit values that were estimated using probit analysis, into the Mahalanobis’ generalized distance formula.

The same approach will be taken here: the trait specific threshold or logit values from the logit models will be inserted in the Mahalanobis D^2 formula. Logit values are considered preferable to probit values for the following reasons:

- 1) Though the standard normal curve has been assumed to represent the probability distribution of trait liability, this has never been shown to be the case. To date, there is no evidence to indicate that the underlying continuous distribution of the

phenotypically expressed non-metric traits is normally distributed. If the assumption is correct, use of the probability distribution of the logistic regression will not affect the results because the logistic density curve is, for practical purposes, the same as the standard normal density curve, the only difference being that the logistic curve has slightly thicker tails (Agresti, 1996:79).

- 2) Parameter estimates produced during the logit modeling procedure have interpretive value. The estimates can be converted directly into log odds ratios, and hence into odds ratios. The latter readily lend themselves to, and are easily understood in discussion of, the results of the study.

The logit values, by population group, are calculated as β (constant term) + population group parameter estimate. As such, the calculated logit value may be interpreted as the *age-and-sex-adjusted* log odds of trait presence for the population group in question. The inclusion of an interaction term *population group*age* or *population group*sex* in the logit model indicates that the population group main effect varies with, and is dependent on, age or sex respectively. Treatment of traits whose model contains an interaction term will be discussed in the Results section.

In summary, logit modeling produces a logit or “threshold” value for each of the 12 population groups to be included in the distance analysis, by individual trait. Within this context the logit value plays the role of the (age-and-sex-adjusted) median of a logistically distributed trait propensity variable over all individuals from a specific population group.

Mahalanobis D^2 (Mahalanobis, 1936; Rao, 1952) is considered the best distance coefficient available for continuous data (Constandse-Westermann, 1972). It was

originally designed to take into account inter-trait correlation and to standardize the data by way of a pooled dispersion matrix (variance/co-variance matrix). In this study a matrix of phi coefficients was used instead of the pooled dispersion matrix and the rationale for this substitution is explained below. D^2 expresses the distance between two population groups and is calculated as follows:

$D^2 = d^T W^{-1} d$ where d represents the column vector with elements d_1, \dots, d_r ; d_i represents the difference in the logit values of the i th trait between population A and population B, for $i=1,2,\dots,r$, and d^T denotes the transpose of the vector d . The expression W^{-1} represents the inverse of the phi coefficient matrix for all traits, i.e. each trait will have its own column and its own row within the matrix, pooling over all population groups.

The mathematical concepts related to the development of, and the matrix operations required for, calculation of Mahalanobis D^2 statistic are complex (Mahalanobis, 1936; Rao, 1952) and are only briefly reviewed here.

Like many other distance statistics developed for the analysis of quantitative data, Mahalanobis D^2 is based on squared Euclidean distance, measured in an orthogonal system, where correlation between traits is zero and the variance is 1 for each trait. Considered geometrically, the addition of a^2 to b^2 , representing the sum of squared differences for two traits between populations A and B, equals the squared length of the difference vector, c^2 . This is reminiscent of Pythagoras' theorem in which the relationship between the hypotenuse and the sides of a right angled triangle is expressed by the equation $a^2 + b^2 = c^2$ (Constandse-Westermann, 1972:18). The incorporation of the pooled dispersion matrix into the original Mahalanobis D^2 formula was intended to take

the inter-trait correlation and the trait variances into account by adjusting the data to fit an orthogonal system with unit variances. In this study a matrix of phi coefficients was used in lieu of the pooled dispersion matrix, to take inter-trait association into account. Phi coefficients were calculated between each pair of traits from data aggregated over all population samples, male plus female, and young plus old. A symmetrical matrix was created in which each trait has its own column and row, and the diagonal is equal to 1 (100% association).

The pooling of all population samples to calculate the phi coefficients for the distance measure follows the same rationale used for pooling population samples prior to calculation of the variance/covariance matrix for Mahalanobis D^2 : It is assumed that each of the populations represented in the study shares the same variance per trait and covariance per pair of traits (Constandse-Westermann, 1972:6). Generally, small sample sizes discourage testing this assumption.

The phi coefficient is the non-parametric equivalent (except for signs) of the Pearson product-moment correlation coefficient, in the sense that the former measures association between two qualitative traits and the latter measures correlation between two quantitative traits. As one of the functions of the pooled dispersion matrix is to take into account potential correlation between pairs of traits, it was assumed that the phi coefficient would do the same.

Logit modeling provides estimates of the constant term (β), and population group, age and sex parameter estimates for all traits. The sum of the constant term and population group parameter estimate represents the threshold value on the trait propensity

scale for each of the 10 (of 14 traits for which a logit model could be produced) and 12 population groups. These were used to create the difference vectors required for the Mahalanobis D^2 formula. Specifically, for a given pair of population samples, the differences between the logit values for traits 1 to 10 are calculated, yielding d_1 to d_{10} . Calculation of Mahalanobis D^2 for each pair of population groups will result in a 12-by-12 matrix of distance coefficients symmetrical about the diagonal, each population group having its own row and its own column; the diagonal entries are, of course, zero.

In view of the criticisms that have been leveled against the Mean Measure of Divergence distance statistic, a general comparison was conducted of the results of the two methods of analysis. Thus, Mean Measure of Divergence distances were calculated based on the raw frequency data used to create the logit models. The formula used is a modification of Smith's MMD, using the Freeman-Tukey inverse sine transformation of the trait frequencies (Sjøvold, 1977) and is as follows:

$$= \frac{\sum_{i=1}^Z (\theta_1^i - \theta_2^i)^2 - \left(\frac{1}{T_1^i + \frac{1}{2}} + \frac{1}{T_2^i + \frac{1}{2}} \right)}{Z}$$

$$\text{where } \theta_1^i = \frac{1}{2} \sin^{-1} \left(1 - \frac{2F_1^i}{T_1^i + 1} \right) + \frac{1}{2} \sin^{-1} \left(1 - \frac{2(F_1^i + 1)}{T_1^i + 1} \right)$$

$$\text{and } \theta_2^i = \frac{1}{2} \sin^{-1} \left(1 - \frac{2F_2^i}{T_2^i + 1} \right) + \frac{1}{2} \sin^{-1} \left(1 - \frac{2(F_2^i + 1)}{T_2^i + 1} \right)$$

and Z = total number of traits.
 T_1^i = total number of left plus right observations in the first skeletal sample for the i th trait.
 T_2^i = total number of left plus right observations in the second skeletal sample for the i th trait.
 F_1^i = number of left plus right sides with trait present in the first skeletal sample.
 F_2^i = number of left plus right sides with trait present in the second skeletal sample.

The Freeman-Tukey transformation was used by Ossenberg (1994) in her publication of distance analysis based on cranial non-metric traits from population groups that are similar in composition to those analyzed in the present study. Both the MMD and Mahalanobis distance were compared with Ossenberg's interpretation of population affinities. In addition, Spearman's r , was used to test the rank-order correlation between the Mahalanobis distance and the MMD distance.

The Mahalanobis distance matrix and MMD distance matrix were subjected to cluster analysis in Systat 6.0 for Windows (1996). Cluster analysis is a multivariate procedure for detecting natural groupings in data and is used mostly as a descriptive or exploratory tool (Kaufman and Rousseeuw, 1990:37). The algorithm chosen to cluster the data is based on what Sneath and Sokal (1973) define as unweighted, agglomerative and hierarchic methods. Though there are numerous linkage methods to choose from, Kaufman and Rousseeuw (1990) make a strong case for the mathematical average. The mathematical average linkage method avoids the extremes introduced by both single linkage (nearest neighbor) and complete linkage (furthest neighbor) methods. The distance between an individual and an extant cluster, or between two extant clusters, is calculated as the average distance between all pairs of members in the respective sets, and the two with the lowest values are fused at that level. Dendrograms were plotted to illustrate the results of the cluster analysis.

In addition, the Mahalanobis and MMD distances were subjected to multidimensional scaling using Systat 6.0 for Windows (1996). Multidimensional scaling is a data reduction technique whereby distance data are represented in as few dimensions as possible such that the interitem distances nearly match the original distances (Johnson and Wichern, 1988). The technique attempts to position a set of points in space such that their pairwise distances correspond as accurately as possible to the observed distances. Obviously, as we move from higher to lower dimensions there is an increase in loss of information.

The fit between the original distances and the distances in the configuration is measured by “stress” and is calculated as the square root of the sum of the squared deviations of the distances in the configuration space from monotone function divided by the sum of the squares in the configuration space (Kruskal, 1964). Kruskal (1964:3) suggests that stress values of .20 are poor, .10 are fair and between .05 and 0 are good to perfect. Kachigan (1991) alternatively suggests that a stress value of .15 or lower is considered satisfactory.

Two-dimensional scaling will be used because those of higher dimensions are difficult to interpret.

CHAPTER IV: RESULTS

Descriptive Statistics

Table 6 contains percentage frequencies of each of the 14 traits by population, age, and sex. Sample size varied trait by trait as a result of differential preservation or retrieval of the particular part of the skeleton where that feature was observed. Total percentage frequencies ranged from 0.5 for *atlas bridge lateral* (White) to 68.0 for *L₁ anticlinal unit* (Late Woodland Amerind).

Twenty-two of the 82 cells representing the young adults contained sampling zeros while only three of the 82 cells representing the old adults contained sampling zeros, a discrepancy due to small sample sizes of young adults. In terms of sex differences, males had 11/82 sampling zeros while females had only 3/82 sampling zeros. Because the overall samples sizes for the two genders were roughly equal, it appeared that certain traits were, in fact, more rare in males than in females. This is explored further in the Discussion section.

Logit Modeling

A logit model was produced for each of the 14 traits (Table 7 and Appendix A). In order to be accepted, the log of the expected cell frequencies of the proposed logit model had to be such that, with the G^2 statistic, there was not a statistically significant difference in data distribution. A probability value of .05 or greater was required and the logit models of the 14 non-metric traits had probability values that ranged from 0.079 for the *atlas bridge posterior* trait to 0.882 for *C₇ costal transverse foramen* (Table 7). Only

TABLE 6. Percentage frequency and total number of observations per trait, by population group, age and gender.

Trait	Population Group	Male						Female						Total					
		Young		Old		Total		Young		Old		Total		Young		Old		Total	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
<i>Sternal aperture</i>	Eskimo	27	0.0	52	1.9	79	1.3	16	6.3	55	0.0	71	1.4	43	2.3	107	0.9	150	1.3
	Aleut	2	0.0	20	0.0	22	0.0	1	0.0	30	6.7	31	6.5	3	0.0	50	4.0	53	3.8
	Kodiak Island	14	0.0	26	3.9	40	2.5	17	5.9	23	0.0	40	2.5	31	3.2	49	2.0	80	2.5
	Amerind ¹	16	6.3	22	9.1	38	7.9	9	11.1	12	16.7	21	14.3	25	8.0	34	11.8	59	10.2
	White	5	0.0	78	3.9	83	3.6	1	0.0	90	4.4	91	4.4	6	0.0	168	4.2	174	4.0
	Black	21	9.5	66	7.6	87	8.1	26	15.4	71	7.4	97	9.3	47	12.8	137	7.3	184	8.7
																			mean = 5.1
<i>Atlas bridge posterior</i>	Eskimo	38	5.3	75	8.0	113	7.1	32	0.0	91	6.6	123	4.9	70	2.9	166	7.2	236	5.9
	Aleut	12	8.3	42	14.3	54	13.0	5	20.0	49	14.3	54	14.8	17	11.8	91	14.3	108	13.9
	Kodiak Island	11	9.1	22	31.8	33	24.2	10	0.0	12	0.0	22	0.0	21	4.8	34	20.6	55	14.6
	Amerind	23	26.1	27	33.3	50	30.0	13	7.7	18	5.6	31	6.5	36	19.4	45	22.2	81	21.0
	White	5	0.0	92	6.5	97	6.2	2	50.0	100	30.0	102	3.9	7	14.3	192	4.7	199	5.0
	Black	23	21.7	74	10.8	97	13.4	27	14.8	73	6.9	100	9.0	50	18.0	147	6.1	197	11.2
																			mean = 11.9
<i>Atlas bridge lateral</i>	Eskimo	37	16.2	74	10.8	111	12.6	31	6.5	90	3.3	121	4.1	68	11.8	164	6.7	232	8.2
	Aleut	12	16.7	41	9.8	53	11.3	4	0.0	49	10.2	53	9.4	16	12.5	90	10.0	106	10.4
	Kodiak Island	11	9.1	22	13.6	33	12.1	10	0.0	13	15.4	23	8.7	21	4.8	35	14.3	56	10.7
	Amerind	23	4.4	27	18.5	50	12.0	13	23.1	18	16.7	31	19.4	36	11.1	45	17.8	81	14.8
	White	5	0.0	92	0.0	97	0.0	2	0.0	99	1.0	101	1.0	7	0.0	191	0.5	198	0.5
	Black	23	4.4	74	0.0	97	1.0	27	3.7	73	1.4	100	2.0	50	4.0	147	0.7	197	1.5
																			mean = 7.7
<i>Atlas transverse foramen defective</i>	Eskimo	36	0.0	66	10.6	102	6.9	28	7.1	81	3.7	109	4.6	64	3.1	147	6.8	211	5.7
	Aleut	12	0.0	40	2.5	52	1.9	5	0.0	48	2.1	53	1.9	17	0.0	88	2.3	105	1.9
	Kodiak Island	9	0.0	20	10.0	29	6.9	9	11.1	11	0.0	20	5.0	18	5.6	31	6.5	49	6.1
	Amerind	24	0.0	31	0.0	55	0.0	13	7.7	18	0.0	31	3.2	37	2.7	49	0.0	86	1.2
	White	5	0.0	92	5.4	97	5.2	2	0.0	94	7.5	96	7.3	7	0.0	186	6.5	193	6.2
	Black	23	21.7	73	9.6	96	12.5	27	0.0	73	8.2	100	6.0	50	10.0	146	8.9	196	9.2
																			mean = 5.1

<i>Lumbar rib</i>	Eskimo	42	16.7	63	17.5	105	17.1	31	16.1	68	8.8	99	11.1	73	16.4	131	13.0	204	14.2
	Aleut	6	50.0	33	9.1	39	15.4	3	0.0	37	10.8	40	10.0	9	33.3	70	10.0	79	12.7
	Kodiak Island	16	12.5	38	18.4	54	16.7	21	14.3	24	8.3	45	11.1	37	13.5	62	14.5	99	14.1
	Amerind	30	20.0	30	16.7	60	18.3	10	10.0	15	26.7	25	20.0	40	17.5	45	20.0	85	18.8
	White	5	20.0	92	13.0	97	13.4	2	0.0	95	4.2	97	4.1	7	14.3	187	8.6	194	8.8
	Black	22	13.6	72	19.4	94	18.1	26	7.7	73	6.9	99	7.1	48	10.4	145	13.1	193	12.4
																			mean =13.5
<i>Six unit sacrum</i>	Eskimo	48	25.0	89	43.8	137	37.2	34	41.2	101	33.7	135	35.6	82	31.7	190	38.4	272	36.4
	Aleut	9	55.6	50	42.0	59	44.1	3	33.3	58	20.7	61	21.3	12	50.0	108	30.6	120	32.5
	Kodiak Island	21	23.8	30	46.7	51	37.3	19	10.5	26	34.6	45	24.4	40	17.5	56	41.1	96	31.3
	Amerind	36	11.1	29	37.9	65	23.1	10	0.0	15	13.3	25	8.0	46	8.7	44	29.5	90	18.9
	White	5	20.0	84	52.4	89	50.6	2	50.0	99	41.4	101	41.6	7	28.6	183	46.4	190	45.8
	Black	23	47.8	74	43.2	97	44.3	27	29.6	74	47.3	101	42.6	50	38.0	148	45.3	198	43.4
																			mean =34.7
<i>S₁ lumbarization</i>	Eskimo	46	47.8	111	43.2	157	44.6	37	48.7	120	35.8	157	38.9	83	48.2	231	39.4	314	41.7
	Aleut	4	50.0	54	55.6	58	55.2	3	33.3	55	23.6	58	24.1	7	42.9	109	39.4	116	39.7
	White	5	0.0	91	28.6	96	27.1	2	0.0	99	17.2	101	16.8	7	0.0	190	22.6	197	21.8
	Black	23	30.4	73	26.0	96	27.1	27	25.9	74	33.8	101	31.7	50	28.0	147	29.9	197	29.4
																			mean =33.2
<i>S₁ cleft neural arch</i>	Eskimo	50	18.0	118	11.9	168	13.7	42	14.3	123	10.6	165	11.5	92	16.3	241	11.2	333	12.6
	Aleut	7	0.0	59	5.1	66	4.6	3	0.0	68	2.9	71	2.8	10	0.0	127	3.9	137	3.7
	Kodiak Island	21	9.5	29	20.7	50	16.0	19	10.5	26	0.0	45	4.4	40	10.0	55	10.9	95	10.5
	Amerind	41	17.1	35	11.4	76	14.5	13	7.7	21	9.5	34	8.8	54	14.8	56	10.7	110	12.7
	White	5	0.0	92	21.7	97	20.6	2	0.0	100	8.0	102	7.8	7	0.0	192	14.6	199	14.1
	Black	23	17.4	74	13.5	97	14.4	27	11.1	74	1.4	101	4.0	50	14.0	148	7.4	198	9.1
																			mean =10.5
<i>High sacral hiatus</i>	Eskimo	45	6.7	98	9.2	143	8.4	37	13.5	113	7.1	150	8.7	82	9.8	211	8.1	293	8.5
	Aleut	9	0.0	59	1.7	68	1.5	3	0.0	62	3.2	65	3.1	12	0.0	121	2.5	133	2.3
	Kodiak Island	21	14.3	28	3.6	49	8.2	18	5.6	25	4.0	43	4.7	39	10.3	53	3.8	92	6.5
	Amerind	38	0.0	29	3.5	67	1.5	13	0.0	16	0.0	29	0.0	51	0.0	45	2.2	96	1.0
	White	5	0.0	91	2.2	96	2.1	2	0.0	98	2.0	100	2.0	7	0.0	189	4.5	196	2.0
	Black	23	4.4	73	2.7	96	3.1	27	3.7	74	0.0	101	1.0	50	4.0	147	1.4	197	2.0
																			mean = 3.7

¹ Late Woodland Amerind, Northern Mississippi Valley .

TABLE 7. Logit model and associated probability value for 14 non-metric traits of the vertebral column based on the dataset of six population samples.

Trait	Logit model	Fit of model		
		G ²	DF	Probability
<i>Sternal aperture</i>	Population	11.80	18	0.857
<i>Atlas bridge posterior</i>	Population + Sex	25.74	17	0.079
<i>Atlas bridge lateral</i>	Population	19.63	18	0.354
<i>Atlas transverse foramen defective</i>	Population	25.05	18	0.124
<i>Axis transverse foramen defective</i>	Null (no effects)	26.50	23	0.278
<i>C₆ double transverse foramen</i>	Population + Age	16.67	17	0.477
<i>C₇ costal transverse foramen</i>	Population + Age	10.48	17	0.882
<i>Cervical rib</i>	Age + Sex	21.90	21	0.405
<i>L₁ anticlinal unit¹</i>	Population + Age + Pop*Age	9.91	10	0.448
<i>Lumbar rib</i>	Sex	18.17	22	0.696
<i>Six unit sacrum</i>	Population + Age + Sex + Pop*Age	15.63	11	0.155
<i>S₁ lumbarization²</i>	Population + Sex + Pop*Sex	7.14	8	0.522
<i>S₁ cleft neural arch</i>	Population + Sex	20.46	17	0.251
<i>High sacral hiatus</i>	Population	11.56	18	0.869

¹ Lack of sufficient data required removal of the White sample in order to produce a logit model for this trait.

² Owing to poor inter-observer replicability (i.e. change in scoring protocol) only data collected by the author were used to produce a logit model for this trait.

atlas bridge posterior ($p=0.079$) was considered to be “barely non-significant”, or of poor fit, while the logit models for the remaining 13 traits were considered “highly non-significant”, or of excellent fit.

Population term

Eleven of the 14 traits contained the population term in their logit model (Table 8). Of these 11, the following four traits contained only the population term in their model: *sternal aperture*, *atlas bridge lateral*, *atlas transverse foramen defective*, and *high sacral hiatus*. Both *C₆ double transverse foramen defective* and *C₇ costal transverse foramen* contained main effects for age in addition to main effects for population, while *L₁ anticlinal unit* contained main effects for population and age in addition to a population*age interaction term. *Atlas bridge posterior* and *S₁ cleft neural arch* contained main effects for sex in addition to main effects for population, while the *S₁ lumbarization* logit model contained main effects for population and sex in addition to a population*sex interaction term. Only the *six unit sacrum logit* model contained main effects for all three variables (population, age and sex). In addition, this logit model contained a population*age interaction term. The three features having no population term in their logit models were *axis transverse foramen defective*, *cervical rib* and *lumbar rib*.

The G^2 statistic can be partitioned, making it possible to assess the contribution of each variable independently of all other variables. This is done by comparing the expected cell frequencies of the previous model in the sequence with the expected cell frequencies when the new term is added. If the difference is significant ($P<0.05$) then the new term contributes significantly to, and should be included in, the logit model. The probability

TABLE 8. Contribution of the population group term as measured by its associated G^2 , degrees of freedom and probability value.

Trait	Logit model	Delta		
		G^2	DF	Probability
<i>Sternal aperture</i>	Population	14.72	5	0.012
<i>Atlas bridge, posterior</i>	Population + Sex	23.14	5	0.000
<i>Atlas bridge, lateral</i>	Population	41.95	5	0.000
<i>Atlas transverse foramen defective</i>	Population	12.44	5	0.029
<i>C₆ double transverse foramen</i>	Population + Age	10.99	5	0.052
<i>C₇ costal transverse foramen</i>	Population + Age	36.31	5	0.000
<i>L₁ anticlinal unit</i>	Population + Age + Pop*Age	227.29	4	0.000
<i>Six unit sacrum</i>	Population + Age + Sex + Pop*Age	26.11	5	0.000
<i>S₁ lumbarization¹</i>	Population + Sex + Pop*Sex	25.56	3	0.000
<i>S₁ cleft neural arch</i>	Population + Sex	13.24	5	0.021
<i>High sacral hiatus</i>	Population	22.17	5	0.000

¹ Lack of sufficient data required removal of the White sample in order to produce a logit model for this trait.

² Owing to poor inter-observer replicability (i.e. change in scoring protocol) only data collected by the author were used to produce a logit model for this trait.

values for the population term in those logit models that included the term, ranged from 0.0 (*atlas bridge lateral*) to 0.052 (*C₆ double transverse foramen*). Though the latter was on the borderline of statistical significance, the expected cell frequencies associated with this model fit the observed data better than the model that did not include the population term. This was determined from an examination of the adjusted residuals. For the logit model that included the population term, there were no statistically significant adjusted residuals, while in the logit model that did not include the population term, there was one statistically significant adjusted residual, that associated with old Eskimo male. In addition, the adjusted residual associated with old Kodiak female approached statistical significance. This example illustrates the importance of critically assessing the fit of each model, based on both G^2 and probability values, in addition to the associated adjusted residuals, as a means of determining the “best” model, as opposed to rigidly adhering to a specific statistical level of significance (Muller and Mayhall, 1971:152).

Age term

Five traits included the age term in their logit models (Table 9). Of these five, only one trait, *cervical rib*, did not include a population term in addition to the age term, and no models included main effects for age only. Of the four with the population term (*C₆ double transverse foramen*, *C₇ costal transverse foramen*, *six unit sacrum*, *L₁ anticlinal unit*) the latter two features also had a population*age interaction term. The probability values associated with the statistical significance of age main effects, ranged from 0.007 (*six unit sacrum*) to 0.033 (*cervical rib*).

Sex term

Six traits included the sex term in their logit models (Table 10). Of these six, the logit models of the following four traits also included population main effects: *atlas bridge posterior*, *six unit sacrum*, *S₁ lumbarization* and *S₁ cleft neural arch*. The *S₁ lumbarization* logit model also included a population*sex interaction term. The *cervical rib* model included age main effects in addition to main effects for sex, while the *lumbar rib* model included sex main effects only. The probability values associated with the statistical significance of sex main effects ranged from 0.0 (*S₁ cleft neural arch*) to 0.015 (*S₁ lumbarization*).

Interaction term

As previously mentioned, three traits included an interaction term in their respective logit models (Table 11). *L₁ anticlinal unit* contained main effects for population and age in addition to an interaction between these two variables. The *six unit sacrum* model contained main effects for population, age and sex in addition to the interaction term population*age. Finally, the logit model for *S₁ lumbarization* included population and sex main effects in addition to an interaction between these two variables. In all three cases the interaction term indicated that the sex and/or age main effects varied by population. In other words, in the case of *L₁ anticlinal unit* and *six unit sacrum*, the population term is not statistically independent of age, and is not statistically independent of sex in the case of *S₁ lumbarization*. The implications of these relationships are explored further in the Discussion.

TABLE 9. Contribution of the age term as measured by its associated G^2 , degrees of freedom and probability value.

Trait	Logit model	Delta		
		G^2	DF	Probability
<i>C₆ double transverse foramen</i>	Population + Age	5.89	1	0.015
<i>C₇ costal transverse foramen</i>	Population + Age	5.75	1	0.016
<i>Cervical rib</i>	Age + Sex	4.55	1	0.033
<i>L₁ anticlinal unit¹</i>	Population + Age + Pop*Age	5.28	1	0.022
<i>Six unit sacrum</i>	Population + Age + Sex + Pop*Age	7.32	1	0.007

¹ Lack of sufficient data required removal of the White population group in order to produce a logit model for this trait.

TABLE 10. Contribution of the sex term as measured by its associated G^2 , degrees of freedom and probability value.

Trait	Logit model	Delta		
		G^2	DF	Probability
<i>Atlas bridge, posterior</i>	Population + Sex	7.62	1	0.006
<i>Cervical rib</i>	Age + Sex	9.05	1	0.003
<i>Lumbar rib</i>	Sex	11.18	1	0.001
<i>Six unit sacrum</i>	Population + Age + Sex + Pop*Age	7.53	1	0.006
<i>S₁ lumbarization¹</i>	Population + Sex + Pop*Sex	5.94	1	0.015
<i>S₁ cleft neural arch</i>	Population + Sex	13.49	1	0.000

¹ Owing to poor inter-observer replicability (i.e. change in scoring protocol) only data collected by the author were used to produce a logit model for this trait.

TABLE 11. Contribution of the interaction terms as measured by their associated G^2 , degrees of freedom and probability value.

Trait	Logit model	Delta		
		G^2	DF	Probability
<i>L₁ anticlinal unit</i> ¹	Population + Age + Pop*Age	23.52	4	0.000
<i>Six unit sacrum</i>	Population + Age + Sex + Pop*Age	9.84	5	0.080
<i>S₁ lumbarization</i> ²	Population + Sex + Pop*Sex	10.58	3	0.014

¹ Lack of sufficient data required removal of the White sample in order to produce a logit model for this trait.

² Owing to poor inter-observer replicability (i.e. change in scoring protocol) only data collected by the author were used to produce a logit model for this trait.

It should be noted that though the population*age interaction term for six unit sacrum has an associated probability of 0.080 it was included in the final model because, without it, the model does *not* fit the data. In addition, the model that contained the interaction term had no statistically significant adjusted residuals while the model that excluded the interaction term had one statistically significant residual, that associated with the Eskimo young female group. As previously mentioned, examination of the adjusted residuals allows one to fine-tune the process of model selection.

Odds Ratios

Table 12 shows odds ratios, their associated upper and lower confidence limits, X^2 and associated probability values by trait and parameters of the logit model. The logit modeling procedure, being based on and producing log odds ratios, requires a “baseline comparison” for each of the terms to be tested. In this study they were “White”, “old adult”, and “female”. Of the eleven logit models that contained a population term, the odds ratios for the population term ranged from 0.18 for Late Woodland Amerinds, *atlas transverse foramen defective* (i.e. ratio of trait present/absent for White to Late Woodland Amerind was 1.00:0.18) to 34.26 for Late Woodland Amerind, *atlas bridge lateral* (i.e. the ratio of trait present/absent for White to Late Woodland Amerind was 1.00:34.26).

Odds ratios are considered statistically significant if the probability value associated with the X^2 is less than 0.05. In addition, if the range between the upper and lower odds ratio confidence limits contained the value 1.0, this also indicates that there is no statistically significant difference in the frequency of the trait compared between the two groups in question (Lilienfeld and Lilienfeld, 1980). Thus, if only odds ratios and their

TABLE 12. Odds ratios and associated confidence intervals, X^2 and probability values per trait, by logit model parameters

Trait / Logit model	Parameter	Odds ratio	OR Confidence Limits		X^2	DF	Probability
			Lower	Upper			
<i>Sternal aperture / Population</i>	Eskimo	0.32	0.07	1.58	1.95	1	0.162
	Aleut	0.94	0.19	4.65	0.01	1	0.935
	Kodiak Island	0.61	0.12	3.01	0.37	1	0.546
	Amerind ¹	2.70	0.87	8.39	2.95	1	0.086
	Black	2.27	0.91	5.67	3.10	1	0.078
<i>Atlas bridge posterior / Population + Sex</i>	Eskimo	1.20	0.52	2.77	0.18	1	0.670
	Aleut	3.05	1.32	7.08	6.76	1	0.009
	Kodiak Island	3.02	1.13	8.12	4.82	1	0.028
	Amerind	4.70	2.04	10.83	13.17	1	0.000
	Black	2.38	1.09	5.19	4.79	1	0.029
	Male	1.93	1.20	3.10	7.30	1	0.007
<i>Atlas bridge lateral / Population</i>	Eskimo	17.57	2.33	132.50	7.73	1	0.005
	Aleut	22.81	2.90	179.28	8.84	1	0.003
	Kodiak Island	23.64	2.78	200.86	8.39	1	0.004
	Amerind	34.26	4.37	268.37	11.32	1	0.001
	Black	3.05	0.31	29.54	0.92	1	0.337

Trait / Logit model	Parameter	OR Confidence Limits				X ²	DF	Probability
		Odds ratio	Lower	Upper				
<i>Atlas transverse foramen defective / Population</i>	Eskimo	0.91	0.40	2.08	0.05	1	0.822	
	Aleut	0.29	0.06	1.33	2.52	1	0.113	
	Kodiak Island	0.98	0.27	3.63	0.00	1	0.980	
	Amerind	0.18	0.02	1.39	2.72	1	0.099	
	Black	1.53	0.71	3.26	1.19	1	0.276	
<i>Axis transverse foramen defective / No Effects</i>								
-								
-								
-								
-								
<i>C₆ double transverse foramen / Population + Age</i>	Eskimo	1.06	0.70	1.62	0.08	1	0.779	
	Aleut	0.97	0.56	1.65	0.02	1	0.898	
	Kodiak Island	0.71	0.39	1.31	1.19	1	0.274	
	Amerind	1.67	0.95	2.93	3.11	1	0.078	
	Black	0.72	0.47	1.10	2.30	1	0.129	
Young Adult	1.43	1.00	2.04	3.87	1	0.049		
<i>C₇ costal transverse foramen / Population + Age</i>	Eskimo	5.70	2.58	12.58	18.54	1	0.000	
	Aleut	1.54	0.50	4.77	0.57	1	0.452	
	Kodiak Island	0.59	0.07	4.81	0.24	1	0.621	
	Amerind	7.32	2.86	18.76	17.19	1	0.000	
	Black	1.18	0.45	3.04	0.11	1	0.739	
Young	0.45	0.22	0.90	5.17	1	0.023		

Trait / Logit model	Parameter	OR Confidence Limits			X ²	DF	Probability
		Odds ratio	Lower	Upper			
<i>Cervical rib / Age + Sex</i>	Young	3.58	1.22	10.48	5.42	1	0.020
	Male	0.15	0.03	0.66	6.25	1	0.012
<i>L₁ anticlinal unit / Population + Age + Pop*Age</i>	Eskimo	0.41	0.21	0.77	7.64	1	0.006
	Aleut	0.26	0.12	0.53	13.49	1	0.000
	Kodiak Island	3.77	1.48	9.61	7.75	1	0.005
	Black	0.05	0.02	0.12	51.77	1	0.000
	Young	1.30	0.55	3.08	0.36	1	0.547
	Eskimo/Young	2.57	0.92	7.18	3.23	1	0.072
	Aleut/Young	1.59	0.29	8.64	0.29	1	0.592
	Kodiak./Young	0.25	0.07	0.94	4.19	1	0.041
	Black/Young	0.16	0.02	1.49	2.58	1	0.108
	<i>Lumbar rib / Sex</i>	Male	2.02	1.32	3.09	10.63	1

Trait / Logit model	Parameter	OR Confidence Limits			X ²	DF	Probability	
		Odds ratio	Lower	Upper				
<i>Six unit sacrum / Population + Age + Sex + Pop*Age</i>	Eskimo	0.71	0.47	1.08	2.53	1	0.112	
	Aleut	0.50	0.30	0.83	7.11	1	0.008	
	Kodiak Island	0.78	0.42	1.43	0.64	1	0.423	
	Amerind	0.45	0.22	0.91	4.88	1	0.027	
	Black	0.94	0.61	1.45	0.08	1	0.777	
	Young	0.42	0.08	2.22	1.05	1	0.306	
	Male	1.45	1.10	1.89	7.10	1	0.008	
	Eskimo/Young	1.70	0.29	9.89	0.35	1	0.553	
	Aleut/Young	4.93	0.63	38.67	2.30	1	0.129	
	Kodiak./Young	0.73	0.10	5.03	0.11	1	0.746	
	Amerind/Young	0.52	0.07	4.09	0.39	1	0.533	
	Black/Young	1.80	0.30	10.84	0.41	0.5	0.523	
	<i>S₁ lumbarization / Population + Sex + Pop*Sex</i>	Eskimo	3.14	1.70	5.79	13.42	1	0.000
		Aleut	1.57	0.71	3.48	1.24	1	0.265
Black		2.29	1.17	4.47	5.90	1	0.015	
Male		1.84	0.92	3.65	2.99	1	0.084	
Eskimo/Male		0.69	0.30	1.57	0.78	1	0.376	
Aleut/Male		2.11	0.74	6.03	1.93	1	0.164	
Black/Male		0.44	0.17	1.10	3.10	1	0.078	

Trait / Logit model	Parameter	Odds ratio	OR Confidence Limits			X ²	DF	Probability
			Lower	Upper				
<i>S₁ cleft neural arch / Population + Sex</i>	Eskimo	0.87	0.52	1.46	0.28	1	0.595	
	Aleut	0.23	0.09	0.61	8.66	1	0.003	
	Kodiak Island	0.70	0.32	1.51	0.85	1	0.357	
	Amerind	0.77	0.38	1.55	0.53	1	0.467	
	Black	0.61	0.32	1.14	2.42	1	0.120	
	Male	2.10	1.39	3.16	12.40	1	0.000	
	Eskimo	4.48	1.53	13.08	7.52	1	0.006	
	Aleut	1.11	0.24	5.03	0.02	1	0.895	
	Kodiak Island	3.35	0.92	12.17	3.37	1	0.066	
	Amerind	0.51	0.06	4.58	0.37	1	0.544	
	Black	0.99	0.25	4.04	0.00	1	0.994	

High sacral hiatus / Population

¹ Late Woodland Amerind, Northern Mississippi Valley.

associated upper and lower confidence intervals were available, these could be used to determine statistical significance of the odds ratios. Examination of Table 12 confirms that both methods produced identical results in terms of indicating statistical significance and thus, for ease of reporting, only probability values were used here to measure statistical significance. Of the 52 population term odds ratios, 20 were statistically significant. Their probability values range from 0.0 for Black, *L₁ anticlinal unit*, and Eskimo and Late Woodland Amerind *C₇ costal transverse foramen*, to 0.029 for Black, *atlas bridge posterior*. Three traits, *atlas bridge posterior*, *atlas bridge lateral* and *L₁ anticlinal unit*, had the highest number of population samples significantly different from Whites, 4/5 samples for the former two and 4/4 for the latter trait.

Note that for both the age and gender terms, there were only two categories and the baseline comparisons were “old adult” and “female” respectively. Therefore, the appearance of either of these two terms in a main effects logit model for a specific trait in and of itself indicated a statistically significant difference between the two categories. This would not be the case for the logit models that contained an interaction term for age or sex: this would indicate statistical dependence of the two (or more) interaction terms, the related main effects being included in the model as a condition of the hierarchy principle of model building.

Of the four logit models that contained an age term, the odds ratios for this term ranged from 0.42 for the young adult cohort, *six unit sacrum* (i.e. ratio of trait present/absent for old to young adult is 1.00:0.42) to 3.58 for the young adult cohort, *cervical rib* (i.e. the ratio of trait present/absent for old to young adult is 1.00:3.58).

Of the four age term odds ratios, two were statistically significant. Their probability values were 0.020 for young adult, *cervical rib* and 0.023 for young adult *C₇ costal transverse foramen*.

The logit model for *L₁ anticlinal unit* contained a population*age interaction term in addition to main effects for population and age. In this model the odds ratio of the young adult cohort was not statistically different from the old adult (OR=1.30, p=0.547).

The logit model for *six unit sacrum* contained a population*age interaction term in addition to main effects for population, age and sex. As was the case for the *L₁ anticlinal unit*, the odds ratio of the young cohort compared to the old cohort was not statistically significant (OR=0.42, p=0.306).

Of the six logit models that contained a term for gender, the odds ratios for this term ranged from 0.15 for *cervical rib* in males (i.e. ratio of trait present/absent for female to male was 1.00:0.15) to 2.10 for *S₁ cleft neural arch* in males (i.e. the ratio of trait present/absent for female to male was 1.00:2.10).

Of the six gender term odds ratios, five were statistically significant. Their probability values ranged from 0.0 for *S₁ cleft neural arch* to 0.012 for *cervical rib* in males. In addition, the probability value of 0.084 associated with the odds ratio of trait presence to trait absence for female compared to male, approached statistical significance for *S₁ lumbarization* trait.

The logit model for *S₁ lumbarization* contained a population*sex interaction term in addition to main effects for population and sex. In this model the odds ratios of the male group was not statistically different from the female group (OR 1.84, p=0.084).

Inter-Trait Association

Table 13 contains the inter-trait association matrix with phi coefficients shown above the main diagonal, and probability values under a null hypothesis of zero association below the main diagonal. Probability values were calculated using the X^2 statistic except when 25% or more of the cells had expected values of less than five. When this occurred Fisher's exact test was used instead. Phi coefficients ranged from 0.0 for *C₆ double transverse foramen - cervical rib* and *S₁ cleft neural arch - high sacral hiatus*, to 0.229 for *atlas bridge posterior - atlas bridge lateral*. The greatest negative phi coefficient was -0.083 for *six unit sacrum - high sacral hiatus*. Of the 78 coefficients, 12 indicated a statistically significant association based on X^2 and Fisher's exact test. Four would be expected by chance under the criterion of a 5% significance level. In summary, from Table 13, *atlas bridge lateral* was the most commonly affected trait: four traits were associated with it. This was followed by *atlas transverse foramen defective*, *C₆ double transverse foramen*, and *six unit sacrum*, all of which had three traits associated with them.

The probabilities of the twelve significant associations ranged from $p=0.061$ for *six unit sacrum - S₁ cleft neural arch*, to $p=0.229$ for *atlas bridge posterior - atlas bridge lateral*. *Sternal aperture* and *cervical rib* were never significantly associated with any other traits.

Assessment of the Fit of the Logit Models, By Trait

Assessment of the fit of each logit model is based on various statistics, the most important of which are the probability values associated with the log likelihood chi-square

TABLE 13. Inter-trait association matrix with phi coefficients above the main diagonal and probability values¹ under a null hypothesis of zero association below the main diagonal². Bolded values are statistically significant (p<0.05).

	STAP	ATA	ATB	ATO	AXO	C6F	C7F	C7R	THLT	LUR	SANO	SASP	SAHL
<i>Sternal aperture</i>	-	0.011	0.022	-0.025	-0.034	-0.068	0.056	-0.031	-0.029	0.021	0.009	0.013	-0.010
<i>Atlas bridge posterior</i>	0.736	-	0.229	-0.039	0.103	0.064	0.042	-0.005	0.043	0.010	0.038	0.013	0.017
<i>Atlas bridge lateral</i>	0.643	0.001	-	-0.065	-0.042	0.111	0.032	-0.032	0.134	-0.026	0.040	0.005	-0.002
<i>Atlas transverse foramen defective</i>	1.000	0.217	0.045	-	0.117	0.036	-0.080	0.017	-0.026	0.011	0.019	-0.037	-0.055
<i>Axis transverse foramen defective</i>	1.000	0.008	0.391	0.006	-	-0.016	-0.017	-0.019	-0.026	-0.007	0.052	-0.059	-0.004
<i>C₆ double transverse foramen</i>	0.084	0.069	0.002	0.312	0.642	-	0.112	0.000	0.023	-0.039	-0.062	-0.011	-0.071
<i>C₇ costal transverse foramen</i>	0.189	0.251	0.429	0.026	1.000	0.002	-	-0.006	0.058	-0.001	-0.073	0.026	-0.009
<i>Cervical rib</i>	1.000	1.000	1.000	0.498	1.000	0.991	1.000	-	0.007	-0.055	-0.034	0.045	0.012
<i>L₁ anticlinal unit</i>	0.429	0.204	0.001	0.457	0.448	0.499	0.104	1.000	-	0.023	-0.034	0.036	0.034
<i>Lumbar rib</i>	0.581	0.778	0.479	0.759	1.000	0.278	0.982	0.236	0.479	-	0.071	0.048	-0.007
<i>Six unit sacrum</i>	0.822	0.289	0.266	0.596	0.151	0.085	0.052	0.376	0.303	0.042	-	0.061	-0.083
<i>S₁ cleft neural arch</i>	0.766	0.711	0.892	0.285	0.160	0.743	0.473	0.201	0.259	0.156	0.043	-	0.000
<i>High sacral hiatus</i>	1.000	0.593	1.000	0.160	1.000	0.045	1.000	0.538	0.288	0.841	0.006	0.978	-

¹ The X² statistic was used to calculate probability values unless 25% or more of cells had expected values of less than 5 in which case Fisher's exact test was used to calculate probabilities.

² Owing to poor inter-observer replicability (i.e. change in scoring protocol) S₁ lumbarization could not be included in the calculation of phi coefficients.

(G^2) and the various adjusted residuals. In addition to identifying which cells of the contingency table contain “outliers” adjusted residuals are also useful for directing the researcher to closer examination of the frequency distribution of the trait among population, age and sex categories. This is particularly useful when the logit model contained only a main effect for a single variable. Consider the logit model “population”. A statistically significant adjusted residual indicated which of the four categories (young male, young female, old male, old female) within a specific population sample exhibited cell frequencies that were significantly different from the frequencies predicted under the accepted logit model.

Adjusted residuals were calculated for each cell in the cross-classified table, and under the assumption of a multinomial distribution and a sufficiently large sample size, each adjusted residual would be approximately distributed as a standard normal variable (i.e. a normally distributed variable with mean equal to zero and variance equal to 1.0). An adjusted residual lesser or greater than -1.96 and 1.96 respectively (i.e. outside the range of approximately two standard deviations) indicates a statistically significant discrepancy between the observed and expected frequencies in the associated cell and serves to identify where the fit of the model is weakened. With a 5% level of significance one out of twenty statistically significant adjusted residuals would be expected by chance.

The following serves as an assessment of the fit of each logit model, by trait, within the context of the associated adjusted residuals, G^2 probability values, and trait frequencies. Table 6 contains percentage frequency data for each of the 14 traits, by

population, age and sex. Table 7 contains logit models and their associated fit, by trait, and Table 14 contains adjusted residuals, by trait.

Sternal aperture

This trait was rarely observed (frequency ranged from 1.3% for Eskimo to 10.2% for Late Woodland Amerind). Though nine of the 24 cells in the cross-classified table contained sampling zeros, when the data were collapsed over population, age and sex the zeros were eliminated. None of the adjusted residuals indicated a significant discrepancy between observed and expected frequencies. They ranged from -1.240 for old male Aleuts to 1.248 for young female Eskimos

Atlas bridge posterior

Though this trait was not rare (frequency ranged from 5.0% in Whites to 21.0% in Late Woodland Amerinds) the fit of its logit model bordered on non-significant ($p=0.079$). Nevertheless, only one category, White young female, indicated a significant discrepancy between the observed and expected frequencies with an adjusted residual of 1.996. All other residuals ranged from -1.660 to 1.616.

Atlas bridge lateral

The percentage frequency of this trait showed substantial variation among populations, ranging from 0.5% for the Whites to 14.8% for the Late Woodland Amerinds. Only one residual approached statistical significance: Eskimo old female at -1.891. All other residuals fell within the range -1.627 to 1.589.

TABLE 14. Adjusted residuals for each trait by population group, age and sex. Bold values indicate statistical significance ($p < 0.05$).

Trait / Logit model	Population	Male		Female	
		Young	Old	Young	Old
<i>Sternal aperture</i> <i>Population</i>	Eskimo	-0.851	0.348	1.248	-1.215
	Aleut	-0.392	-1.240	-0.277	0.753
	Kodiak Island	-0.842	0.408	0.763	-1.079
	Amerind ¹	-0.555	-0.170	0.092	0.753
	White	-0.641	-0.080	-0.287	0.200
	Black	0.133	-0.330	1.103	-0.510
<i>Atlas bridge posterior</i> <i>Population + Sex</i>	Eskimo	-0.618	0.063	-1.660	1.048
	Aleut	-0.932	-0.599	0.661	0.932
	Kodiak Island	-0.802	1.616	-1.450	-1.588
	Amerind	0.132	0.982	-0.773	-1.230
	White	-0.826	-0.027	1.996	-0.298
	Black	0.945	-0.913	1.172	-0.381
<i>Atlas bridge lateral</i> <i>Population</i>	Eskimo	1.589	0.787	-0.366	-1.891
	Aleut	0.663	-0.132	-0.936	-0.040
	Kodiak Island	-0.178	0.427	-1.506	0.515
	Amerind	-1.627	0.525	0.787	0.218
	White	-0.225	-0.965	-0.142	0.624
	Black	0.904	-1.507	0.783	-0.109

<i>Atlas transverse foramen defective</i>						
<i>Population</i>						
Eskimo	-2.053	1.551	0.321	-0.821		
Aleut	-0.679	0.263	-0.439	0.089		
Kodiak Island	-1.066	0.666	0.564	-1.179		
Amerind	-0.749	-0.852	1.462	-0.649		
White	-0.801	-0.317	-0.507	0.480		
Black	1.806	0.119	-2.281	-0.290		
<i>Axis transverse foramen defective</i>						
<i>No Effects</i>						
Eskimo	-1.311	0.080	-1.196	0.399		
Aleut	1.003	0.813	1.536	-0.152		
Kodiak Island	1.228	0.768	1.933	-0.794		
Amerind	-1.011	-1.243	-0.677	0.716		
White	-0.535	-0.391	-0.338	-2.381		
Black	1.372	-0.023	0.264	-0.849		
<i>C₆ double transverse foramen</i>						
<i>Population + Age</i>						
Eskimo	0.622	1.541	-0.734	-1.519		
Aleut	-0.207	0.786	0.130	-0.800		
Kodiak Island	1.723	-0.529	0.814	-1.402		
Amerind	-0.660	0.490	0.097	0.175		
White	-0.343	0.053	-1.608	0.228		
Black	-0.473	0.352	0.124	-0.155		
<i>C₇ costal transverse foramen</i>						
<i>Population + Age</i>						
Eskimo	0.158	-1.344	0.509	0.910		
Aleut	-0.581	0.476	-0.367	-0.333		
Kodiak Island	-0.395	-0.930	-0.559	0.934		
Amerind	-0.365	1.128	-0.367	-0.602		
White	-0.469	0.311	-0.297	-0.244		
Black	0.499	0.572	0.426	-1.095		

<i>Cervical rib</i> <i>Age + Sex</i>	Eskimo	-0.924	-0.593	-1.631	0.008
	Aleut	-0.354	-0.375	-0.577	0.360
	Kodiak Island	-0.354	-0.346	1.375	-0.847
	Amerind	2.415	-0.325	0.884	-0.758
	White	-0.354	-0.787	-0.577	-0.073
	Black	-0.760	-0.687	-2.039	0.931
<i>L₁ anticlinal unit</i> <i>Population + Age + Pop*Age</i>	Eskimo	0.060	1.460	-0.069	-1.380
	Aleut	0.000	-0.223	0.000	0.216
	Kodiak Island	-0.469	0.630	0.415	0.829
	Amerind	-0.292	0.935	0.473	-1.048
	Black	-0.964	-0.640	0.566	0.597
<i>Lumbar rib</i> <i>Sex</i>	Eskimo	0.032	0.208	1.286	-0.019
	Aleut	1.892	-1.232	-0.747	0.399
	Kodiak Island	-0.445	0.318	0.805	-0.097
	Amerind	0.506	0.027	0.121	2.003
	White	0.207	-0.916	-0.610	-1.771
	Black	-0.369	0.663	-0.219	-0.636
<i>Six unit sacrum</i> <i>Population + Age + Sex + Pop*Age</i>	Eskimo	-1.488	0.145	1.769	-0.142
	Aleut	0.196	1.060	-0.347	-1.101
	Kodiak Island	0.427	0.162	-0.542	-0.181
	Amerind	0.369	0.664	-1.169	-1.084
	White	-0.537	0.179	0.816	-0.167
	Black	0.496	-1.135	-0.485	1.145

<i>S₁ lumbarization</i>² <i>Population + Sex + Pop*Sex</i>	Eskimo	0.441	-0.285	1.208	-0.682
	Aleut	-0.208	0.057	0.359	-0.087
	White	-1.777	0.318	-0.859	0.090
	Black	0.357	-0.204	-0.655	0.386
<i>S₁ cleft neural arch</i> <i>Population + Sex</i>	Eskimo	0.278	-1.422	1.203	0.742
	Aleut	-0.844	0.044	-0.384	0.265
	Kodiak Island	-0.581	1.035	0.559	-1.947
	Amerind	0.373	-0.607	-0.007	0.296
	White	-1.433	0.769	-0.643	-0.625
	Black	0.733	0.360	0.964	-2.070
<i>High sacral hiatus</i> <i>Population</i>	Eskimo	-0.464	0.228	1.007	-0.568
	Aleut	-0.641	-0.303	-0.370	0.484
	Kodiak Island	1.258	-0.688	-0.170	-0.548
	Amerind	-0.892	1.008	-0.522	-0.579
	White	-0.454	0.105	-0.287	0.000
	Black	0.685	0.408	0.554	-1.742

¹ Late Woodland Amerind, Northern Mississippi Valley.

² Owing to poor inter-observer replicability (i.e. change in scoring protocol) only data collected by the author was used to produce a logit model for this trait.

Atlas transverse foramen defective

This was another rare trait. Frequencies ranged from 1.2% in the Late Woodland Amerind to 9.2% in the Black population sample. In addition, eleven of the 24 cells in the cross-classified table contained sampling zeros. When the data were collapsed over population, age and sex during the logit model building procedure, the cells containing zero frequencies were eliminated. Two of the 24 adjusted residuals indicated a statistically significant deviation between the observed and expected cell frequencies. They included Black young female at -2.281 and Eskimo young male at -2.053. In addition, Black young male approached statistical significance, at 1.806. All other residuals ranged from -1.179 to 1.551.

These residuals indicated a pattern of data distribution in which both young Black subsamples and young Eskimo male subsamples did not conform. Examination of the data associated with the four Eskimo subsamples indicates that the young males defined the lower limit of the frequency range with a frequency of 0.0%; the remaining three frequencies ranged from 4.6% to 6.0%. The same was true for the two adjusted residuals observed in the Black young population subsamples; they defined the lower and upper limits of the frequency range. The young females had a zero frequency and young males had a frequency of 21.7%, while the old females had a frequency of 8.2% and the old males had a frequency of 9.6%. Whether or not this is random or has biological meaning needs to be considered in more detail.

Axis transverse foramen defective

Axis transverse foramen defective was rarely observed (frequency ranged from 1.0% for White to 8.5% for Kodiak Island), and nine of the 24 cells in the cross-classified table had zero individuals with the trait present. Despite the paucity of data, when they were collapsed over population, age or sex, the marginal totals did not contain sampling zeros. One adjusted residual was statistically significant: White old female at -2.381. One adjusted residual approached significance: Kodiak Island young female at 1.933. The range for the other residuals was -1.311 to 1.536.

The percentage frequency for the young female Kodiak Island subsample was the second highest with a value of 15.4% (young female Aleut was highest at 20.0% but this was based on a sample size of only five individuals; and here it was important to keep in mind that the formula for adjusted residuals takes into account both sample size and variance). Old White females had a frequency of 0.0%, as did several other subsamples, but the sample size for the former (99 individuals) was substantially larger than the others.

C₄ double transverse foramen

The frequency of this trait ranged from 33.5% in Blacks to 56.0% in Late Woodland Amerinds. None of the adjusted residuals indicated a statistically significant deviation; young Kodiak males showed the greatest deviation with a value of 1.723. All other residuals ranged between -1.608 and 1.541.

Within the context of the logit model building procedure, the model containing just main effects for age was also correct. Essentially, when the population term was added to the age main effect model, the new term bordered on statistical significance with a

probability value of 0.052. Equally important, the fit of the age + population logit model showed a substantial improvement when the population term was added to the model ($p=0.477$). The fit of the age only logit model was $p=0.187$. Here, the choice of the best model was aided by an examination of the adjusted residuals. In the model containing only age effects there was one statistically significant deviation between the observed and expected cell frequencies, and two deviations that approached statistical significance (-1.942 and, to a lesser degree 1.844). In the model containing both main effects for age and population there were no statistically significant deviations. Thus, the latter model represented the data more accurately.

C₇ costal transverse foramen

The percentage frequencies for this trait varied substantially among populations and ranged from 2.2% for Kodiak Island to 20.6% for Late Woodland Amerind. Though seven of the 24 cells in the cross-classified table presented a zero frequency, when the data were collapsed over population, age or sex all were eliminated. None of the adjusted residuals were statistically significant. The highest residual was -1.344 associated with the old Eskimo male group. All other residuals ranged from -1.095 to 1.128.

Cervical rib

Only 14 *cervical ribs* were observed in the total sample. Not surprisingly, 17 of the 24 cells of the cross-classified table had sampling zeros (frequencies ranged from 1.1% for White to 7.0% for Eskimo). Nonetheless, when the data were collapsed over population, age, or sex all of the marginal totals had a trait frequency of at least one. Because of the number of zero frequencies in the cross-classified table, it was not possible to test the

effect of the age*sex interaction term, which would have been the next step in the model building procedure. Two of the adjusted residuals were significant: young Late Woodland Amerind male and young Black female with values of 2.415 and -2.039 respectively. Other adjusted residuals range from -1.631 to 1.375.

Because this model contained two main effects, age and sex, it was difficult to determine whether the former, latter, or combination of terms was responsible for the breakdown of the model. Examination of the frequency data suggested that deviation of the young Late Woodland Amerind male subsample (with a frequency of 12.4%) was gender related, as all other *male* cell frequencies were zero compared to all other *young adult* cell frequencies which ranged from 0.0% to 18.8%. The frequency of 0.0% for the young Black *female* subsample was probably also related to gender because 6/12 cells of the female versus 9/12 cells of the *young adult* group contained zero frequencies. That is, the young Black female frequency of 0.0% is different from six of the twelve female groups and three of the twelve young adult groups.

L₁ anticlinal unit

This was another trait characterized by substantial inter population variation. Frequencies ranged from 1.5% for Whites to 68.0% for Late Woodland Amerinds. Because three of the four cells of the cross-classified table representing the White population sample contained zero frequencies (young and old male and young female), marginal totals for both males and young adults were zero. As a result, it was not possible to build a logit model for this trait. Instead, a customized data set that excluded the White population group was created for the model building procedure. The resulting logit model

included main effects for population and age in addition to a population*age interaction term. None of the adjusted residuals reached statistical significance. The other residuals ranged from -1.380 to 1.460.

Lumbar rib

A common variant, this ranged in frequency from 8.8% in Whites to 18.8% in Late Woodland Amerinds. Only one adjusted residual was statistically significant: old Late Woodland Amerind female at 2.003. The other residuals fell within the range of -1.771 to 1.892.

Six unit sacrum

The frequency of this trait ranged from 18.9% in Late Woodland Amerinds to 45.8% in Whites. There were no adjusted residuals indicating a significant deviation of the observed from the expected frequencies. The greatest deviation was observed in the young Eskimo female with an adjusted residual of 1.769. The other residuals fell within the range -1.488 to 1.145.

S₁ lumbarization

Difficulties with the scoring protocol for this trait required that the analysis be restricted to data collected by the author. A logit model was built using the following four population groups: Eskimo, Aleut, White and Black. The frequencies ranged from 21.8% to 41.7% for Whites and Eskimos respectively. None of the adjusted residuals were statistically significant. They ranged from -1.777 to 1.208.

S₁ cleft neural arch

This was a relatively common trait (frequencies ranged from 3.7% for the Aleuts to 14.1% for Whites). There was only one adjusted residual that indicated a significant deviation between the observed and expected cell frequencies: old Black female at -2.070. Old Kodiak Island female approached significance with a value of -1.947. All other residuals ranged from -1.433 to 1.203.

In addition, though the logit model contained two terms, population and gender, examination of the percentage frequencies for each of the variables indicated that in the two instances where the adjusted residuals approached significance (old Kodiak Island female and old Black female) the deviation appeared to derive from *population*. The Kodiak Island old female percentage frequency of 0.0% deviated more from 9.5%, 20.7% and 10.5%, representing the remaining three Kodiak Island categories, than from the 0.0% (three populations) to 14.3% representing the 12 female categories. The situation is similar for the Black old female population sample. The frequency of 1.4% is substantially different from 17.4%, 13.5%, and 11.1% of the remaining three Black categories than the three 0.0% frequencies included in the 11 remaining female groups.

High sacral hiatus

Though this trait was rare, a considerable inter-population variation in trait frequency occurred. The frequencies ranged from 1.0% for Late Woodland Amerinds to 8.5% for Eskimos. Eight of the 24 cells of the cross-classified table contained sampling zeros, but these were eliminated when the data were collapsed over population, age or sex categories. None of the adjusted residuals indicated a significant deviation between

observed and expected frequencies. Old Black female showed the greatest deviation with a value of -1.742. All other residuals fell within the range of -0.892 and 1.258.

The frequency of the old Black female subset was 0.0%. Because the logit model contained only the population term, the deviation between the observed and expected frequencies resulted from the Black subsample variation; the frequencies of the remaining three subsamples are 4.4%, 2.7% and 3.7%.

Distance Analysis

Appendix B contains information pertaining to percentage frequency of each of the 13 traits, by population group, age and sex. In order to perform distance analysis certain adjustments and exclusions had to be made. First, as already noted, *S₁ lumbarization* was excluded because those data scored only by N.S.Ossenberg (for Kodiak Island, Illinois Hopewell, and Late Woodland samples) could not be used owing to a revision in scoring protocol for this feature. Secondly, because the distance analysis was based on logit models, the inability to model *sternal aperture*, *axis transverse foramen defective* and *cervical rib*, owing to insufficient data, meant that these three features also had to be excluded. In addition, because of insufficient data, the North Pacific Coast Amerind group had to be removed from the *lumbar rib* logit modeling procedure. A summary of the logit models for 10 traits used in distance analysis is presented in Table 15. Other fine-tuning preparatory to distance analysis is outlined below.

The population + age + sex model associated with *six unit sacrum* did not fit the data well ($p=0.056$). The “best” model is the one that also included the population*age interaction term which fit the data with a probability value of 0.128. Unfortunately, lack

TABLE 15. Logit model and associated probability value for 13 non-metric traits of the vertebral column based on the data set of 12 population groups to be used in distance analysis.

Trait	Logit model	Fit of model		
		G ²	DF	Probability
<i>Sternal aperture</i>	insufficient data	-	-	-
<i>Atlas bridge posterior</i>	Population + Sex	40.56	32	0.143
<i>Atlas bridge lateral</i>	Population	30.96	33	0.569
<i>Atlas transverse foramen defective</i>	Population	41.43	33	0.149
<i>Axis transverse foramen defective</i>	not enough data	-	-	-
<i>C₆ double transverse foramen</i>	Population + Age	41.50	32	0.121
<i>C₇ costal transverse foramen</i>	Population	34.98	33	0.374
<i>Cervical rib</i>	insufficient data	-	-	-
<i>L₁ anticlinal unit</i> ¹	Population + Age + Pop*Age	20.12	22	0.576
<i>Lumbar rib</i> ²	Sex + Population	30.81	29	0.374
<i>Six unit sacrum</i>	Population + Age + Sex	43.20	30	0.056
<i>S₁ cleft neural arch</i> ³	Population + Sex + Pop*Sex	20.36	21	0.499
<i>High sacral hiatus</i>	Population	35.05	33	0.371

¹ Distance analysis used hand-calculated logit values.

² This trait was modeled without the North Pacific Coast Indian group. Distance analysis used hand-calculated logits.

³ Distance analysis used hand-calculated logit values .

of sufficient data for this trait, particularly in the smaller skeletal samples, resulted in unacceptably high standard errors associated with the parameter estimates of the interaction term model. Thus, the parameter estimates derived from the no-interaction model had to be used for the distance analysis.

Two traits contained an interaction term in their logit models, *L₁ anticlinal unit* and *S₁ cleft neural arch*. Presence of an interaction term indicated that the age or sex main effect was not statistically independent of the population main effect. For *L₁ anticlinal unit* the age effect varied by, and was therefore not consistent among, all 12 population groups. Because the age effect was not consistent across all population groups the population group parameter estimate was not “*age-and-sex adjusted*”.

The intuitive solution was to calculate two distinct logit models for each of the traits. The *L₁ anticlinal unit*, which contained a population*age interaction term in the original model, would require a logit model for young adults and another one for old adults. Similarly, *S₁ cleft neural arch*, which contained a population*sex interaction term in the original model, would require a logit model for males and a logit model for females. Unfortunately, insufficient data in young adult subsample (*L₁ anticlinal unit*) and male subsample (*S₁ cleft neural arch*) precluded the creation of separate logit models for these subsamples. Instead, logit or threshold values were hand-calculated for the two age cohorts for the former trait and two gender subsamples for the latter trait. Hand-calculated logit values are simply the log odds of trait present to trait absent, by population.

Four distance matrices were then created from the four separate data sets. Each data set included the logit or threshold values of each of the eight traits that did not contain an interaction term plus one of the following four, as appropriate:

- 1) Log odds of the young adult cohort for *L₁ anticlinal unit* and log odds of males for *S₁ cleft neural arch*.
- 2) Log odds of the young adult cohort for *L₁ anticlinal unit* and log odds of females for *S₁ cleft neural arch*.
- 3) Log odds of the old adult cohort for *L₁ anticlinal unit* and log odds of males for *S₁ cleft neural arch* trait.
- 4) Log odds of the old adult cohort for *L₁ anticlinal unit* and log odds of females for *S₁ cleft neural arch*.

A comparison of the distance matrices, using Spearman's rank-order correlation coefficient, indicated that in the case of *L₁ anticlinal unit* the distance matrices for young and old adults, by gender, were highly correlated (females: $r_s=0.73$, males: $r_s=0.75$); similarly, in the case of *S₁ cleft neural arch* the distance matrices for males and females, by age cohort, were highly correlated (young: $r_s=0.93$, old: $r_s=0.90$). Therefore, a decision was made to combine young-old frequencies for *L₁ anticlinal unit* and male-female frequencies for *S₁ cleft neural arch*. The hand-calculated logit or threshold values were subsequently determined and incorporated into the distance calculation computer program.

Table 16 contains the Mahalanobis distance measures above the main diagonal. They range from 0.143 between Plains Amerinds and Illinois Hopewell to 2.052 between

TABLE 16. Distance matrix with Mahalanobis D^2 distances above the main diagonal and MMD distances below the main diagonal.

	Saint				North							
	Arctic/ Inupiaq Eskimo	Lawrence Island Eskimo	South Alaskan Eskimo	Ingalik (Athabascan)	Aleut	Kodiak Island	Coast Indian	Plains Indian	Late Woodland Indian	Illinois Hopewell Indian	White	Black
Arctic/Inupiaq Eskimo	0	0.354	0.360	0.390	0.409	0.687	0.573	0.362	0.680	0.321	1.289	0.768
St. Lawrence Island Eskimo	0.026	0	0.232	0.429	0.375	0.582	0.230	0.358	0.635	0.154	1.126	0.475
South Alaskan Eskimo	0.101	0.072	0	0.543	0.560	0.424	0.380	0.272	0.584	0.194	1.707	0.922
Ingalik (Athabascan)	0.104	0.090	0.072	0	0.189	0.446	0.503	0.278	0.656	0.373	0.972	0.448
Aleut	0.029	-0.001	0.075	0.050	0	0.434	0.479	0.312	0.368	0.258	1.203	0.539
Kodiak Island	0.130	0.083	0.050	0.160	0.094	0	0.836	0.346	0.650	0.267	2.052	1.059
North Pacific Coast Indian	0.075	0.008	0.093	0.012	0.000	0.133	0	0.550	0.993	0.445	1.488	0.794
Plains Indian	0.076	0.028	0.037	0.042	0.043	0.051	0.045	0	0.416	0.143	1.339	0.740
Late Woodland Indian	0.137	0.107	0.072	0.110	0.086	0.030	0.124	0.031	0	0.355	2.016	1.159
Illinois Hopewell Indian	0.056	0.016	0.017	0.064	0.021	0.006	0.039	-0.005	0.034	0	1.395	0.613
White	0.129	0.140	0.324	0.183	0.142	0.429	0.139	0.226	0.365	0.262	0	0.239
Black	0.075	0.073	0.249	0.137	0.065	0.300	0.077	0.163	0.250	0.171	0.017	0

Kodiak Island and White. It appeared that the White population sample was the most distant or most distinct from all others with all distances greater than 1.000 except for the Athabascan sample at 0.972, and the Blacks at 0.239. The Black sample also exhibited some of the largest distances, except when compared to Whites. The Black sample was most distant from Late Woodland Amerind at 1.159 and Kodiak Island at 1.059.

Table 16 contains the MMD distance measures below the main diagonal. The calculations were restricted to the same 10 traits used for the Mahalanobis distance calculations. They range from -0.005 between Plains Amerind and Illinois Hopewell Amerind to 0.429 between Kodiak Island and White. It appeared that the White population group was the most distant or most distinct from all other groups with distances ranging from 0.129 to 0.429. However, the distance between Whites and Blacks was much less at only 0.017.

Table 17 contains MMD distances below the main diagonal and their associated standard deviations above the main diagonal. MMDs which are less than two times their standard deviation are not significant as was the case for eight of the 65 MMDs; i.e. in terms of this particular trait battery the population samples did not differ significantly from each other. Five of these were related to the Illinois Hopewell Amerind sample: its MMDs for St.Lawrence, South Alaskan Eskimo, Kodiak Island, North Pacific Coast Amerinds and Plains Amerinds were insignificant. In addition, the distance between Illinois Hopewell and Aleut was barely significant.

TABLE 17. Distance matrix with MMD distances below the main diagonal and their associated standard deviations above the main diagonal. Bolded values are NOT statistically significant.

	Saint					North									
	Arctic/ Inupiaq Eskimo	Lawrence Island Eskimo	South Alaskan Eskimo	Ingalik (Athabaskan)	Alcut Island	Kodiak Island	Pacific Coast Indian	Plains Indian	Amerind	Late Woodland Indian	Illinois Hopewell Indian	White	Black		
Arctic/Inupiaq Eskimo	0	0.011	0.006	0.014	0.006	0.007	0.016	0.008	0.007	0.010	0.004	0.004	0.004		
St. Lawrence Island Eskimo	0.026	0	0.011	0.020	0.012	0.013	0.021	0.014	0.012	0.016	0.010	0.010	0.010		
South Alaskan Eskimo	0.101	0.072	0	0.014	0.006	0.007	0.016	0.008	0.006	0.010	0.004	0.004	0.004		
Ingalik (Athabaskan)	0.104	0.090	0.072	0	0.015	0.016	0.025	0.017	0.015	0.019	0.013	0.013	0.013		
Alcut	0.029	-0.001	0.075	0.050	0	0.008	0.017	0.008	0.007	0.011	0.005	0.005	0.005		
Kodiak Island	0.130	0.083	0.050	0.160	0.094	0	0.017	0.009	0.008	0.012	0.006	0.006	0.006		
North Pacific Coast Indian	0.075	0.008	0.093	0.012	0.000	0.133	0	0.018	0.017	0.021	0.015	0.015	0.015		
Plains Indian	0.076	0.028	0.037	0.042	0.043	0.051	0.045	0	0.009	0.013	0.007	0.007	0.005		
Late Woodland Indian	0.137	0.107	0.072	0.110	0.086	0.030	0.124	0.031	0	0.011	0.005	0.005	0.005		
Illinois Hopewell Indian	0.056	0.016	0.017	0.064	0.021	0.006	0.039	-0.005	0.034	0	0.009	0.009	0.009		
White	0.129	0.140	0.324	0.183	0.142	0.429	0.139	0.226	0.365	0.262	0	0	0.003		
Black	0.075	0.073	0.249	0.137	0.065	0.300	0.077	0.163	0.250	0.171	0.017	0	0		

It was important to recognize that a non-significant distance does not indicate that the two population groups are the same. Sjøvold (1977:30) explains

Instead a non-significant result indicates that the two parent populations are not possible to distinguish on the available data. Therefore, it is not reasonable to talk about a divergence between them. Whether this is caused by too small sample sizes or an unfavourable set of traits may be a question of discussion in each particular case.

Finally, two of the MMD distances were negative: Plains Amerind and Illinois Hopewell at -0.005 and Aleut and St.Lawrence Island Eskimo at -0.001. Because cluster analysis and MDS program are unable to process negative data, a correction factor of 0.015 was added to each MMD distance, so that all distances were then above zero in value but without change in their rank order.

Spearman's rank-order correlation test was applied to compare the Mahalanobis and MMD distance measures. The 0.79 correlation is highly statistically significant and indicates that the two techniques produce similar results.

CHAPTER V: DISCUSSION

Biological Interpretation of Logit Models

The odds ratios produced by logit modeling provide a simple, quantitative method for interpreting the relationship among variables. Because the statistical technique used in this study has not been widely applied within the context of non-metric trait research, comparisons with data of this kind are impossible. Thus, in addition to odds ratio data, percentage frequency data were also used for interpretive and comparative purposes.

Each of the 14 traits were examined separately, according to the three descriptive variables, with an emphasis on those terms that were included in the logit model. In addition, an attempt was made to decipher patterns of trait distribution by population group, age and sex, based on the odds ratio data.

Table 6 contains percentage frequency data for each of the 14 traits, by population group, age and sex, and Table 7 contains the “best” logit model and their associated fit, for each of the 14 traits. Table 12 contains odds ratios, and lower and upper confidence limits in addition to X^2 , degrees of freedom, and probability values for each of the parameter estimates associated with a trait’s logit model. These Tables provide the reference data for the following section.

Sternal aperture

The logit model identified for this trait included only the population group variable. *Population.* When each of the five population samples were individually compared to Whites none had an associated odds ratio indicating a significant difference in trait

frequency. Both the Late Woodland Indian and Black samples approached statistical significance with odds ratios of 2.70 (confidence interval from 0.91 to 5.67) and $p=0.086$ for the former, and 2.27 (confidence interval from 0.87 to 8.39) and $p=0.078$ for the latter.

In terms of frequency, the literature suggests that *sternal aperture* occurs most often in Blacks. With the exception of the Late Woodland Amerind sample, this pattern was also observed in the present study, though the percentage frequency of 8.7% was lower than the 13% reported for East Africans (Ashley, 1956) and the 11.5% reported for American Blacks (McCormick, 1981). The 4% frequency reported by Ashley (1956) for a sample of "Europeans" is identical to that observed in the White sample of the present study. The same is true of the mixed Aleut-Eskimo sample studied by Saunders (1978) in which she reported a frequency of 2.7%, as compared to the 2.0% observed in the present study. It should be noted that there was a substantial amount of overlap in the sample used in this study and the one used by Saunders (1978): The Aleut samples were essentially identical, while the individuals in Saunders' (1978) Eskimo sample were subsumed within the current Eskimo sample. Finally, the 10.2% frequency observed in Late Woodland Amerinds analyzed in the present study was close to the 10% frequency observed in an Ontario Iroquois skeletal sample (Anderson, 1963).

In terms of geographic location, the Eskimo, Aleut and Kodiak Island samples all represent northern maritime populations: they were also similar in trait frequency when compared to the White population sample, while the remaining two population samples, Black and Late Woodland Amerind, were not. Whether the similarity in frequency of the three northern groups has biological meaning, needs to be investigated.

Age. The logit model did not include a main effect for age. The young Eskimo, Kodiak Island and Black subsamples had a higher frequency of this feature than their respective old cohorts, while the young Aleut, Late Woodland Amerind and White subsamples had a lower frequency of this feature than their respective old cohorts. This inconsistency partially explains why no age effect was revealed for *sternal aperture*. The rare occurrence of the anomaly and small sample sizes for young adults hampered definitive analysis of adult age effects.

Sex. The final logit model did not include a main effect for sex. Other researchers (Ashley, 1956; McCormick, 1981) report that *sternal aperture* occurs more frequently in males. However, in the present study there appeared to be a trend in the opposite direction: Aleut, Late Woodland Amerind, White and Black females have higher frequencies than do their respective males, while the Eskimo and Kodiak Island females and males have essentially equal frequencies. (1.3% and 1.4% for the former and 2.5% for both sexes in the latter).

Evaluation. The pattern of male-female differences may support the hypothesis that the *sternal aperture* trait represents an hypostotic trait (reduced bone growth or retarded skeletal development), since such a trait is predicted to be more common in females than males as a result of sexual dimorphism in size. It might also be predicted to be more common in younger than older individuals if general bony growth occurring with advancing age resulted in the defect being obliterated. Though not identified in the logit modeling procedure, an hypostotic trend was apparent in that, of the four populations showing sex differences, females had the trait more frequently than males. However,

comparison of frequencies between young and old adults revealed no trend supportive of the “hypostotic trait hypothesis”.

Two points need to be made with regards to the hypostotic trait hypothesis and *sternal aperture*. Firstly, the *sternal aperture* forms during early fetal development and it is not clear to what extent sexual dimorphism affects the axial skeleton primordia at this stage. Secondly, the prediction that the frequency of an hypostotic trait would decrease with increasing age is based on the assumption that bone continues to grow throughout adulthood. Though the size of the *sternal aperture* varies among individuals, the single report that describes the contents of the aperture (fibroadipose tissue and small vessels) did not identify any areas of ossification (Cooper, et al., 1988). Classification of this trait as hypostotic is probably misleading.

The early developmental stage at which this trait becomes manifest suggests that it is at least partially genetically controlled. The logit model supported this observation: The population group variable alone explained the pattern of trait distribution in the cross-classified table. Of particular interest is the fact that the frequencies observed in the six population samples were almost identical to those previously reported for these groups. Could it be that the genetic basis of this trait has reached a level of stability such that the frequencies are consistent across major geographical “populations”? I suggest that the evidence presented here strongly indicates a genetic basis for *sternal aperture* whereby this feature could be useful in forensic identification and population studies. Moreover, the absence of age and sex effects makes it amenable to a simpler statistical analysis than used in the current study.

Atlas bridge posterior

The logit model produced for this trait combined main effects for both population group and sex. Unfortunately, there were not enough data to test the fit of a logit model that included a population group*sex interaction term. The latter model might have improved the fit of the otherwise accepted model, which was barely non-significant ($p=0.079$).

Population. When compared to the White population sample, all other populations except Eskimo showed a significant difference in trait frequency. Their odds ratios ranged from 4.70 (confidence interval from 2.04 to 10.83) for the Late Woodland Amerinds to 2.38 (confidence interval from 1.09 to 5.19) for Blacks. That is, the Late Woodland Amerinds had the trait almost five times as often as Whites, and the Blacks have the trait just over two times as often as the Whites. Both the Aleut and Kodiak Island samples exhibited the feature approximately three times as often as Whites. Again, the geographic proximity of the Aleut and Kodiak Island groups to one another was noteworthy.

Comparative frequencies from the literature include 13% reported for a skeletal sample of American Blacks (a combination of individuals from the Todd collection and a collection curated at the Museum of Natural History in New York City: Taitz and Nathan, 1986), which is very close to the 11.2% observed in the Black sample under study here. The frequency of 5.0% observed in the present White sample, however, was substantially less than the 9.0% reported from a radiographic sample of Canadian Whites (Saunders and Popovich, 1978) and 12.2% for a skeletal sample of American Whites respectively (Ossenfort, 1926). The latter sample is described by Ossenfort as consisting of specimens

from the collection of the Department of Anatomy, Washington University, and some “negros” from the United States National Museum. This could be the beginning of the Terry collection which was accessioned between 1910-1940 and was originally stored at the School of Medicine, Washington University, St. Louis (Bornstein and Peterson 1966:139). Though many researchers have studied this trait, most have combined manifestation of both partial and complete bony bridge into a single trait, thus making data comparisons difficult.

Sex. The gender term in the final logit model indicated a significant difference in frequency of the trait between males and females. The odds ratio indicated that males had the trait almost twice as often as females (OR=1.93, confidence interval 1.20 to 3.10). This was in agreement with the majority of reports which indicate that the trait occurs more frequently in males than females (Ma, 1993; Ossenfort, 1926; Romanus and Tovi, 1964; Saunders and Popovich, 1978; Selby et al., 1955).

Though Saunders (1978) found no significant gender difference in trait frequency in an Amerind skeletal sample, the difference found in the present case of Late Woodland Amerinds from Northern Mississippi Valley appeared to be large: 30.0% for males and 6.5% for females. On the other hand, Saunders’ (1978) observation of no gender difference in a pooled Aleut-Eskimo sample is in closer agreement to the values reported here: males 9.0%, and females 7.9%.

Five of the six population samples had higher male than female frequencies. The difference was particularly marked in Late Woodland Amerinds (noted above) and Kodiak

Island, males 24.2% and females 0.0%. Among Aleuts there was no apparent gender difference, males 13.0% and females 14.8%.

Age. Though the ratio of complete to incomplete posterior bridge has been shown to increase with advancing age, the final logit model indicated that *atlas bridge posterior* is age stable. This agreed with Saunders' (1978) observation of a lack of statistical difference in trait frequency between young and old adult age groups within two Amerind skeletal samples and a combined Eskimo-Aleut skeletal sample. Of the six population groups included in the present study, two have a greater frequency in the young, two have a greater frequency in the old, and two have very similar frequencies in the two cohorts.

Evaluation. As noted in the introductory chapter, there is disagreement as to whether this trait represents a cranial border shift (Von Torklus and Gehle, 1972), a caudal border shift (Barnes, 1994) or neither of the two. As it is classified as an hyperostotic trait, it can be evaluated within this context. Hyperostotic traits are predicted to be more common in males because of their generally more robust skeletal development, and older adults, because of age related bone growth. The former prediction was borne out by the logit model: males had the trait twice as often as the females and five of the six population groups had higher male versus female frequencies. On the other hand, the same cannot be said of the age term; not only was it not included in the logit model, but also the population group frequency data defied a trend in any direction.

When the population group term was added to the null or no effects model, there was a highly significant difference in the expected cell frequencies between the two models ($p=0.000$), indicating that the population group variable was largely responsible for the

observed pattern of data distribution. There was a statistically significant difference in trait frequency for four population groups, when compared to the White population group.

This trait has a sufficient genetic component to be valid in distance analysis. Moreover, the population variability indicated that it would be useful in ethnogenetic research and should therefore be included in the definitive suite of axial skeletal variants to be used in distance analysis.

Atlas bridge lateral

Only the population group variable was included in the *atlas bridge lateral* logit model. As this trait has not been well studied, relatively few publications are available for comparison with the present work.

Population. Four of the five population samples had odds ratios indicating a significant difference when compared to the baseline White samples. Each of the four odds ratios were highly significant, ranging from 34.26 (confidence interval 4.37 to 268.37) in the Late Woodland Amerind group to 17.57 (confidence interval 2.33 to 132.50) in the Eskimo group. The Black sample had an odds ratio of 3.05 which was not significant.

The large odds ratios reflected the marked variation in frequency of this trait together with the fact that it occurred only once in the baseline White sample, which served as the comparison for all other groups. The frequencies ranged from 0.5% in Whites to 14.8% in Late Woodland Amerinds.

Age. Previous researchers have not been successful in determining if, and to what extent, *atlas bridge lateral* is affected by skeletal changes during adulthood. That an age main

effect was not included in the final logit model was not surprising: three of the population groups had a higher frequency in their young adult group (Eskimo, Aleut and Black), two had a higher frequency in their old adult group (Kodiak Island and Late Woodland Amerind) while the White sample had approximately equal frequencies, (0.0% and 0.5%) in young and old.

Sex. The logit model for this trait indicated that gender did not influence expression of this variant. Two population groups had a higher frequency in their male group (Eskimo, Aleut), two had a higher frequency in their female group (Kodiak Island, Late Woodland Amerind) and two had approximately equal frequencies in their respective gender groups (White and Black). Ma (1993) reports that males exhibit the trait twice as often as females in a combined Eskimo-Kodiak sample. Substantial overlap exists between Ma's sample and the present samples; and when the Eskimo and Kodiak samples used in the present study were combined, males and females exhibited frequencies of 12.5% and 4.7% respectively. In Ma's (1993) Amerind-Aleut sample, males exhibit the trait as often as females. Again, in view of the overlap between the two studies, it is not surprising to find that when the Aleut and Late Woodland Amerind population groups were combined the male and female trait frequencies also were very close: 11.7% and 13.1%, respectively.

Evaluation. There has been no discussion so far of this trait as representing either a cranial or caudal border shift. Nevertheless, its positive association with the *atlas bridge posterior* (Table 13) suggested that whatever shift direction is represented in one variant is also represented in the other. It is an hyperostotic trait, but unlike the *atlas bridge posterior*, the *atlas bridge lateral* did not show the expected pattern of trait distribution

between the sexes: Only two population groups had a higher frequency in males than females. Like *atlas bridge posterior*, *atlas bridge lateral* did not show the expected pattern of trait distribution between the ages: Only two groups had a higher frequency in old than young adults.

The marked inter-population variability was reflected in the large odds ratios. Only the Black sample did not differ significantly from the White baseline sample. In addition, the significance of the population group variable strongly supported the assumption that manifestation of this trait is at least partially genetically controlled. The absence of age and gender effects indicated that it could be employed in a simple distance statistic. A comparison of the odds ratios for *atlas bridge posterior* with those for *atlas bridge lateral* (Table 12) suggested that the latter would be both more informative in ethnogenetic research and also more powerfully discriminating in forensic applications.

Atlas transverse foramen defective

The logit model for this trait included only a population group main effect. In addition to population group however, age and sex will be discussed briefly though there is a lack of literature pertaining to this trait.

Population. None of the odds ratios indicated a significant difference in frequency between Whites and any of the five other population samples. The odds ratios ranged from 0.18 (lower and upper confidence limits of 0.02 and 1.39 respectively) in the Late Woodland Amerind sample to 1.53 (lower and upper confidence limits of 0.71 and 3.26 respectively) in the Black sample.

Ossenfort (1926) reports *atlas transverse foramen defective* to occur with a frequency of 6% in a sample of American Blacks and 9% in a sample of American Whites. In contrast, the Black sample here exhibited a frequency of 9.2% and the White sample a frequency of 6.2%

Age. Though Saunders (1978) observed a decrease in the frequency of *atlas transverse foramen defective* throughout the adult age period, the present logit model indicated no significant adult age cohort difference. There was an age trend observed in the present study, though its direction was the reverse of that reported by Saunders. Four of the six populations had a higher frequency of the trait among old adults than young adults, and only two (Late Woodland Amerind and Black) exhibited the reverse. However, in view of the rare occurrence of this anomaly together with the small sample sizes for the young cohort, we should not regard the present findings definitive of the age pattern of the trait.

Sex. A main effect for sex was not detected during the logit modeling procedure. A summary of the descriptive statistics revealed, albeit in a simplistic way, the lack of a consistent pattern. In the Aleut sample, trait frequency was calculated as 1.9% for both the male and female groups. The Late Woodland Amerinds and Whites had a lower male frequency while the other three populations (Eskimo, Kodiak Island, Black) had a lower female frequency. Unfortunately, additional data are not available for comparison.

Evaluation. As this trait is categorized as hypostotic it should occur more frequently in females and young adults. However, the logit model failed to show this predicted pattern. It was negatively associated with the presumably hyperostotic atlas bridging traits, as would be predicted.

In terms of population group variation, though none of the odds ratios were statistically significant, the fact that the population group variable was included in the logit model indicated that it was responsible for the observed pattern of data distribution. The data presented here were consistent with the assumption that there is a sufficient genetic component to expression of *atlas transverse foramen defective* to include it among non-metric traits used for population studies. The fact that there are no age or sex effects makes this trait amenable to less complicated distance analysis than that presented here.

Axis transverse foramen defective

This trait showed significant positive association with *atlas transverse foramen defective* (Table 13), to be discussed further in the section “Inter-trait Association”. Surprisingly, the logit models that best fit each of the two transverse foramen defective traits were completely different: no single variable occurred in both.

A major impediment to thorough investigation of this trait is its very low incidence. It occurred even less often than *atlas transverse foramen defective*, and unless very large samples are available, may not be amenable to the logit modeling procedure.

Data for this anomaly generated the only logit model that did not include main effects for at least one of the three variables. However, it was important to keep in mind that the “no effects” logit model is not a default model resulting from lack of data: standard errors associated with the population group, age and sex main effects models were well within acceptable range. Thus, the no effects model seemed to be the best one; this trait simply was not affected by population group, age or sex. Each of the three variables is briefly discussed below.

Population. It is difficult to evaluate the meaning of the differences in frequencies observed among the six populations. The White sample had the lowest frequency at only 1.0% and the Kodiak Island and Aleut groups had the highest at 8.5% and 5.3% respectively. As was the case for the *atlas bridge posterior*, Kodiak Island and Aleut were closer in frequency to each other than to any other population group.

Age. Three of the populations (Aleut, Kodiak, Black) showed a higher frequency in the young cohort, and three of the population groups (Eskimo, Late Woodland Amerinds, White) showed a higher frequency old cohort. The largest age discrepancies were in Aleuts and Kodiak Islanders with young adult frequencies of 12.5% and 14.3% and old adult frequencies of 3.8% and 3.8% respectively.

Sex. Three of the populations (Aleut, White and Black) had a higher frequency in males than in females. Eskimos exhibited frequencies of 2.1% and 2.8% and Kodiak Islanders exhibited frequencies of 8.7% and 8.3% for males and females respectively, indicating no difference between the sexes. Late Woodland Amerind data hinted at a higher female (4.2%) versus male (0.0%) incidence.

Evaluation. Despite the presumed hypostotic nature of this trait, an examination of the frequency data revealed no effects by gender or age which would corroborate this classification.

Aside from the difficulties that arise from the statistical analysis of such a rare trait, it did not appear to have much potential use either in population studies, or forensic case work where an unknown individual was compared to a large reference database of known

sex and geographic/racial origin. Essentially, removal of this feature from a working trait list would not eliminate valuable information.

C₆ double transverse foramen

The logit model for *C₆ double transverse foramen* included main effects for population group and age. Duplication or bridging of the transverse foramen also occurred with varying frequency in the third, fourth and fifth cervical vertebrae, and its expression in these vertebrae is associated with that of the sixth cervical vertebra. In the past, researchers have dealt with this inter-trait association by combining the frequency of double transverse foramen observed in all four vertebrae as a group into a single trait: “double transverse foramen of cervical vertebrae three to six”. It has been common practice also to include manifestation of both incomplete and complete bony bridges in the category trait present. Thus, despite the common occurrence of this trait, much of the available literature lacks comparable data.

Population. None of the odds ratios indicated a significant difference in trait frequency between each of the five population groups when compared to the baseline White sample. The Late Woodland Amerind approached significance with an odds ratio of 1.67 (confidence intervals from 0.95 to 2.93). In terms of percentage frequencies, Whites had the lowest 33.5%, and Late Woodland Amerind the highest 56.0%.

For the Amerind samples Saunders (1978) reported a frequency of only 15.1%, while in this study (using a wholly different sample) the number was much higher at 56.0%. On the other hand, because of the major overlap between our respective samples, less

variation was observed between the combined Eskimo-Aleut sample: 33.0% in Saunders' (1978) study and 41.9% in the present study.

Age. Main effects for age were included in the logit model but, contrary to what would be expected if this trait belonged in the hyperostotic class, the young adult age group exhibited the trait 1.43 times more often than the old adult age group. In addition, this trait has been observed in immature (Anderson, 1963), newborn and fetal skeletons (Saunders, 1978), which is inconsistent with to the pattern expected for an hyperostotic trait.

Four of the six population groups had a higher frequency in young adults compared to old adults. Conversely, the White sample exhibited a greater frequency in the old adult age group, and the Late Woodland Amerinds exhibited approximately equal frequencies for young and old: 56.4% and 55.6%.

Sex. A main effect for sex was not included in the final logit model. Eskimo, Aleut and Kodiak Islanders had a higher frequency in males versus females while the remaining three populations had approximately equal frequencies: 33.7% and 33.3% for Black males and females respectively; 55.1% and 57.7% for Late Woodland Amerind males and females respectively and 39.2% for both the White males and females.

As was the case for the population group comparison, Saunders (1978) reported lower figures than did the present author: 35.0% for the combined Eskimo-Aleut male subsample compared to the 46.4% observed here and 31.3% for the respective female subsample compared to the 33.9% observed here. Again, the Amerind comparisons, being based on different samples, show the greatest discrepancy: 18.0% for males and 11.8% for females

in Saunders' (1978) sample, compared to 55.1% for males and 57.7% for females in the current study.

Evaluation. This is a classic example of an hyperostotic, or excess bone growth, trait. More interesting than the observation that it did not vary in frequency between males and females, is the fact that it occurred significantly more often in young compared to old adults. It is difficult to envision a scenario in which the bony bridge recedes or is resorbed throughout adulthood. An understanding of the morphological significance of this trait, hypothesized to result from pressure exerted by the vertebral artery (Le Double, 1912) and possibly related primarily to variations in the vertebral vein as well as artery, is needed in order to explain the observed pattern.

In addition to the fact that the population group term occurred in the logit model, the potential of this trait is further supported by the substantial range observed between the population group with the lowest frequency (White) and the population group with the highest (Late Woodland Amerind). *C₆ double transverse foramen* appeared to have a substantial genetic component, and because it occurred with such high frequency, should be useful in a trait list designated for population distance studies. Research focusing on its development and relation to blood vessels is highly recommended in order to address the confusion with regards to its classification as an hyperostotic trait.

C₇ costal transverse foramen

The logit model for this trait was the same as that for the *C₆ double transverse foramen*: population + age. To date this trait has not been well studied though both

Buikstra (1972) and Saunders (1978) make special note of it and suggest an etiology independent of other accessory foramina observed in the cervical vertebrae.

Population. The odds ratios associated with the Eskimo and Late Woodland Amerind samples indicated a significant difference in trait frequency when compared to Whites. The Eskimo odds ratio indicated that the trait occurs almost six times more frequently (OR=5.70, confidence interval 2.58 to 12.58), and the Late Woodland Amerind odds ratio indicates that it occurs just over seven times more frequently (OR=7.32, confidence interval 2.86 to 18.76) than in the White baseline sample. In terms of frequencies, Jackes' (1977) report of 5.0% for a Huron ossuary sample is substantially less than the 20.6% observed in the Late Woodland Amerind sample analyzed in the present study.

Age. In direct opposition to the pattern observed for the *C₆ double transverse foramen*, this trait occurred most frequently in old adults. The odds ratio of old to young was 1.00:0.45. Trait frequencies were consistently higher in the old compared to young adults for all six population groups.

Sex. A main effect for sex was not included in the logit model. Both Eskimo and Kodiak Island males exhibited a higher frequency than females. In the other four populations the opposite was true.

Evaluation. As it represents an area on the costal portion of the transverse process which is deficient in bone, the costal foramen would be considered as an hypostotic trait. The fact that it increased in frequency with advancing age, though it would be expected to decrease, reflected the confusion this trait presents with regards to distinguishing it from manifestation of increased porosity resulting from the normal aging process. That is, as

the amount of porosity in the bone increased, it was increasingly difficult to distinguish between the *costal transverse foramen* and normal age related porosity. Inter and intra-observer agreement tests confirm this (Chapter II). This phenomenon also may account for its apparent increase with advancing age.

The contribution of the population group term to the final model was highly significant ($p=0.000$). Specifically, when the population group term was added to the previous model (in this case the null or “no effects” model) a comparison of the expected cell values between the two models indicated a highly significant difference. Thus, it can be concluded that this trait is highly effective in distinguishing among population groups. This is a trait likely having a substantial hereditary component, and is recommended for inclusion in a trait list intended for distance analysis.

Cervical rib

The correct logit model for this trait included main effects for age and sex but not population group. Because the population group variable did not contribute to its logit model, in addition to the fact that it was rarely observed, *cervical rib* likely would not be useful for distance analysis.

Age. Young adults exhibited the trait 3.58 times more frequently (lower and upper confidence limits of 1.22 to 10.48) than old adults. This was significant ($p= 0.020$).

The Kodiak Island and Late Woodland Amerind samples were responsible for the observed age effect: The young cohort had substantially more individuals with the trait present than the old cohort. The frequencies in the two young adults were 14.3% and 13.8% for Kodiak Island and Late Woodland Indian population groups respectively.

Alternatively, both old adult age groups are zero for Kodiak Island and Late Woodland Amerind. The four other populations (Eskimo, Aleut, White and Black) exhibited sampling zeros in young adults and 1.1%, 2.0%, 1.1% and 2.2% respectively in their old adult cohorts.

Sex. The odds ratio for trait presence/absence in females as compared to males was 1.00:0.15 (upper and lower confidence limits of 0.03 to 0.66 respectively). In other words, females had the trait almost seven times more frequently than males. This is contradicted in Honeij (1920), who hypothesizes that the trait occurs more frequently in males. On the other hand, Steiner (1943) reports the trait to be more frequent in females.

In this study, the percentage frequency of *cervical rib* was consistently lower in males than in females, and except for the Late Woodland Amerind sample (6.5% to 8.0% for males and females respectively) all the other population samples had no males with the trait present. Among Kodiak Islanders, the female percentage frequency was 9.7%, but four other female subsample frequencies were low, ranging from 1.7% to 3.2%.

Population. To reiterate, given the rare occurrence of this anomaly it was difficult to determine if the frequency varies among populations, even though the logit model indicated that it does not. When the population group variable was added to the age + sex logit model the probability associated with the additional term was very high, $p=0.277$, indicating that the expected cell frequencies of the three term model were similar to those of the two term model.

Shmorl and Junghanns (1971) suggest that the frequency of *cervical rib* varies between 0.5% and 1.0%. Lanier (1939) reports a frequency of 2.0% in a sample of White

males and 1.0% in a sample of Black males. As previously noted, Lanier's sample was derived from the Terry collection, the same skeletal material that provided the sample for the White and Black samples used in the present study. In this study the White male frequency and Black male frequency were both 0.0% while the White (male and female) frequency was 1.1% and the Black (male and female) frequency was 1.6%.

Evaluation. This was one of only three traits that did not contain the population group term in their logit model. In addition, the trait was rare (though observed in 7.1% of individuals in the Late Woodland Amerind sample) and was difficult to score consistently. Given a large enough sample size, and a diverse geographical representation *cervical rib* may show a sufficient population effect to be useful for distance analysis.

Cervical rib represents an unequivocal manifestation of cranial shift at the cervicothoracic border. Failure of the costal element to fuse with the transverse process, or hypertrophy of the costal element, results in its manifestation. Because it develops at an early age, it might be expected to be age stable throughout adulthood, but as the odds ratio of 1.00:3.58 (old to young adult) indicated, it decreased in frequency with advancing age. Fusion of the cervical rib with the vertebra is likely the cause.

The reason why it occurred more often in females was puzzling, though there is some evidence that cranial shifts are more common in females (Barnes, 1994:80).

L₁ anticlinal unit

As previously explained, the White population sample had to be excluded from the logit modeling procedure. By default, the Late Woodland Amerind samples became the baseline to which the other four population groups were compared.

The logit model created for *L₁ anticlinal unit* included main effects for both population group and age in addition to a population*age interaction term.

Population. All four odds ratios were significant, ranging from 0.05 (lower and upper confidence limits of 0.02 and 0.12 respectively) for Blacks to 3.77 (lower and upper confidence limits of 1.48 and 9.61 respectively) for Kodiak Islanders. That is, Late Woodland Amerinds had the trait 20 times more frequently than Blacks, and the Kodiak Islanders had the trait almost four times more frequently than Late Woodland Amerinds. In addition, the Late Woodland Amerind sample showed the trait almost two and a half times more frequently than the Eskimo sample and almost four times more frequently than the Aleut. Obviously, a considerable amount of inter-population variation in trait frequency characterized this feature.

Several references corroborate this finding. Specifically, Stewart (1932) reports a frequency of 20.0% for *L₁ anticlinal unit* in an Alaskan Eskimo skeletal sample which is less than half of the 52.0% observed in the current study (a major portion of Stewart's Eskimo sample of 107 individuals was included in, but contributed less than half to, the present Eskimo sample). The 34% frequency observed in a Huron ossuary skeletal sample (Jackes, 1977) is again, approximately half of the 52.0% observed in the present Late Woodland Amerind population group. Whether these discrepancies reflect true biological differences or result from methodological differences is unknown. Finally, Lanier's (1939) 12% frequency observed in a sample of American Black males was compared to the 5.2% observed in the present study sample of Black males (and 7.1% observed in the Black male and females). Lanier's 9% observed in a sample of American White males, is

compared to the 0.0% observed in the present sample of White males (and 1.5% observed in the White males and females). Again, Lanier's sample was derived from the Terry collection and consists only of males. The discrepancies in the indigenous samples may reflect true biological variation as it existed among these population groups.

Age. The odds ratio indicated that young adults exhibited L_1 anticlinal unit 1.30 (confidence interval ranges from 0.55 to 3.08) times more often than the old adults but the difference was not significant ($p=0.547$). Examination of the frequency data indicate that Eskimo, Aleut and Late Woodland Indian have a higher frequency of trait present in young adults and Kodiak Island and Black have a higher frequency of trait present in old adults. In the logit model building procedure, the addition of the age term to the population main effects model indicated that the difference between the expected cell values of the former compared to the latter was significant ($p=0.022$). Nevertheless, for both of these main effects logit models, the fit was unacceptable and indicated that when the expected cell frequencies under the proposed logit model were compared to the observed cell frequencies, there was a highly significant difference.

*Population*Age Interaction term.* The population + age main effects model did not fit the data ($p=0.002$) With the addition of the population*age interaction term the probability value associated with the G^2 statistic indicated a non-significant difference between the observed and expected cell frequencies ($p=0.448$). It is within the two-factor interaction term that the age term contributed to the final logit model. In terms of odds ratios, that associated with the Kodiak Island young adult group is significant at 0.25 (confidence interval from 0.07 to 0.94). The young Eskimo adult group also approached statistical

significance ($p=0.0721$) with an odds ratio of 2.57 (lower and upper confidence limits of 0.92 and 7.18 respectively).

Sex: The lack of a sex effect in the logit model needed to be addressed. Both Eskimos and Late Woodland Amerinds had a greater frequency of the trait in their male versus female subsamples while the other four populations had a greater female than male frequency. Though the lack of significant sex differences corroborated with Merbs' (1974) data, the trend observed here corroborated the female preponderance reported by Stewart (1932).

Evaluation. *L₁ anticlinal unit* represents a caudal shift at the thoracolumbar border. The fact that a population term was included in the model was expected, as border shifts occur as an early developmental process and are strongly influenced by genetic factors (Kuhne, 1932, 1934, 1936 in Barnes, 1994). In addition, the population group term, when added to the null model, is highly significant ($p=0.000$)

It was one of three traits whose logit model includes an interaction term. The age and age*population interaction terms were difficult to interpret. Activity induced bone remodeling of the apophyseal joints may be involved. Axial rotation of the trunk occurs in the thoracic region (Aiello and Dean, 1990), thus the presence of an additional vertebra capable of thoracic type rotation, would increase the range of rotation. Certain activities that require strenuous and repeated trunk rotation, such as kayaking and harpooning (Merbs, 1983), may exert mechanical stress in the area thus causing a caudal shift of the anticlinal unit during an individual's lifetime. Two of the population groups exhibited an increase in trait frequency with advancing age (Kodiak and Black) while three (Eskimo,

Aleut and Late Woodland) showed a decrease. The frequency of the trait makes it easy to study, and a population/genetic component is strongly supported; this trait has the potential to be useful in distance analysis research. Unfortunately the interaction between the population group and age terms could prove to be problematic. More research needs to be done in order to determine the nature of the observed pattern of data distribution.

Lumbar rib

The logit model for this trait included only a main effect for sex.

Sex. The odds ratio of 2.02 (confidence interval from 1.32 to 3.09) was significant ($p=0.001$) and indicated that males exhibit the trait two times more frequently than females. Five population groups (except Late Woodland Amerind with male and female percentage frequencies of 18.3% and 20.0% respectively) had a higher frequency of males than females exhibiting the trait. These data supported Shmorl and Junghanns's (1971) claim that the trait occurs more often in males, but contradicted both Epstein's (1976) and Steiner's (1943) claim that it occurs more often in females. Other research indicates that *lumbar rib* occurred with equal frequency in the two genders (Saunders, 1978).

Age. The logit model did not include a main effect for age though previous research indicates that adult age changes do occur but vary by population (Saunders, 1978). A trend to population*age interaction was also observed in this study, with three (Eskimo, Aleut and White) having a higher frequency of the trait in the young compared to the old adult age group, and three (Kodiak Island, Late Woodland Amerind and Black) having a higher frequency of the trait in the old compared to the young adult age group. It was

noted, further, that this trend paralleled the population*age interaction characteristic of *L₁ anticlinal unit*.

Population. When the population group term was added to the sex main effect logit model, the expected cell frequencies did not change significantly between the two models, and the high probability value associated with the population group term ($p=0.432$) in this study indicated that it did not contribute to the final model. Indeed, Lanier (1939) reports the lumbar rib to occur with equal frequency in Black and White males. This can be compared to their respective frequencies in the present study: 18.1% and 13.4% for males and 12.4% and 8.8% for males and females respectively. Merbs (1974) also studied this trait but combined it with *L₁ anticlinal unit*, to identify the presence of a caudal shift at the thoracolumbar border. He reported the caudal shift so defined to occur in 40% of Canadian Eskimos (substantially greater than the 14.2% observed for *lumbar rib* in the present aggregate Eskimo sample) and 26% of Northwest Coast Amerinds (also higher than the 18.8% observed in the Late Woodland sample from the Northern Mississippi Valley). No doubt the inclusion of *L₁ anticlinal unit* increased the frequencies observed in Merbs' study, but it was interesting to note that the higher frequency is in his Eskimo versus Amerind sample, while in the present study the difference was reversed with respect to the Eskimo-Amerind comparison.

Evaluation. This is the third trait that did not include the population group term in the logit model. As does *L₁ anticlinal unit*, *lumbar rib* represents a caudal shift at the thoracolumbar border and the relationship between these two traits will be explored in the Inter-trait Association section below. Considering *lumbar rib*'s early developmental

origin, one would expect a genetically based population effect. In addition, as was observed with *cervical rib*, one would expect it to decrease in frequency with advancing age, as a result of fusion to the vertebral body. Neither of these variables appeared to influence trait expression.

Six unit sacrum

This was the only logit model containing main effects for all three variables. Each term contributed significantly to the final logit model, and the population*age term, which improved the overall fit of the model, approached significance. As previously noted, inclusion of the interaction term improved the fit by reducing the number of adjusted residuals that were significant. In addition, the fit of the model that did not include the interaction was barely non-significant ($p=0.062$).

Population. Two of the five odds ratios associated with the population group term were significant: Aleut, with an odds ratio of 0.50 (confidence interval of 0.30 to 0.83) and probability value of 0.008, and Late Woodland Amerind with an odds ratio of 0.45 (confidence interval of 0.22 to 0.91) and probability value of 0.027. In other words, the White sample exhibited the trait two times more frequently than the Aleut, and just over two times (2.22) more frequently than the Late Woodland Amerind sample.

Whites had the highest incidence at 45.8% and the Late Woodland Amerinds had the lowest at only 18.9%, followed by Kodiak Island at 31.3%, and Aleut shown to be significantly different than Whites, at 32.5%. Merbs (1974) reports a frequency of 44% in a Canadian Eskimo series. Most of individuals in that series were included in the current Eskimo sample for which a *six unit sacrum* frequency of 36.4% was calculated. The 26%

observed in Merbs' (1974) sample of Northwest Coast Amerinds is also higher than the 18.9% observed in the present Amerind sample from the Northern Mississippi Valley.

Age. In all population samples except Aleut the frequency of *six unit sacrum* was higher in the old adult compared to the young adult age cohort. The odds ratio of old to young adults was 1.00:0.42 (lower and upper confidence limits of 0.08 to 2.22 respectively). In other words, older individuals had the trait almost two and a half times more frequently than younger ones. However, this difference was not significant ($p=0.306$).

Sex. The odds ratio associated with this variable was 1.45 (confidence interval from 1.10 to 1.89), was highly significant ($p=0.008$). That is, males exhibited the trait almost one and a half times more frequently than females.

Males had higher frequencies than females in each of the six populations, though the Eskimo and Black differences were minimal (37.2% versus 35.6%, and 44.3% versus 42.6%, respectively).

Merbs (1974) notes the trait to occur in 54% of males and 35% of females in the Canadian Eskimo sample he studied, a more striking gender difference than that observed for Eskimos in the present study.

Population*Age Interaction term. The odds ratios for this term ranged from 0.52 (confidence interval of 0.07 to 4.09) in the young Late Woodland Amerind adults to 1.80 (confidence interval of 0.30 to 10.84) in the young Black adults. None of the odds ratios were statistically significant, though the presence of the interaction term in the model implied an absence of statistical independence of the population group and age terms.

Evaluation. Portions of this logit model made intuitive sense: The age main effect was expected, old adults exhibiting a higher frequency of the trait compared to young adults, as fusion of vertebrae in this area (particularly the coccyx) tends to occur during the normal aging process. The sex effect, males exhibiting the trait more often than females, can be explained by size differences, the general trend for variation from the normal number of vertebrae being towards an increase in males and a decrease in females (de Beer Kaufman, 1974; Bornstein and Peterson, 1966; Tulsı, 1972). The population group term, when added to the no effects model, was highly significant and supported the potential utility of this trait for distinguishing among various population groups.

The population*age interaction term likely reflects the pattern in Aleuts, the only population in which the otherwise consistent pattern of an increase in trait frequency with advancing age did not conform. It is difficult to envision a situation where a sacral vertebra would become detached from the main sacral unit over time. It is more likely that the apparent Aleut age difference resulted from sample size problems, The young subsample having a total of only 12 individuals, six of whom had *six unit sacrum*. This would be easy to confirm by building a new logit model based on the present sample omitting Aleuts.

To summarize, the population/genetic basis of this trait appeared to be strong. Therefore the trait should be useful in distance analysis, particularly if the confusion resulting from the interaction term can be resolved.

S₁ lumbarization

The final model for *S₁ lumbarization* included main effects for population group and sex in addition to a population*sex interaction term.

Population. Two of the three odds ratios associated with the population group term were statistically significant. The Eskimo sample exhibited the trait just over three times more frequently (OR=3.14, confidence interval 1.70 to 5.79), and the Black sample presented it almost two and a half times more frequently (OR=2.29, confidence interval 1.17 to 4.47), than the White baseline sample.

Whites had the lowest incidence (21.8%), followed by Blacks at 29.4%, Aleuts at 39.7% and Eskimos at 41.7%. Based on these numbers one would expect that a significant odds ratio for Blacks as compared to Whites would imply a statistically significant odds ratio for Aleuts as compared to Whites. This was puzzling, and inspection of subsample figures in Table 6 shed no light on it.

Previous research indicates that *S₁ lumbarization* does vary between geographical population groups, but inconsistent and poorly defined scoring protocols frustrate attempts to compare results from one report to another. Merbs (1974) distinguishes between two manifestations of lumbosacral transitional vertebra and reports lumbarization in 34.3% of a Canadian Eskimo skeletal sample and 32.9% of a Northwest Coast Amerind skeletal sample. Unfortunately, because of revision in scoring protocol between N.S.Ossenberg's data collection beginning in 1963 and the phase beginning with this project in 1994, there was no Amerind sample in the present study large enough to compare with Northwest Coast Amerind. Merbs' Eskimo sample, which is subsumed

within the Eskimo sample used in the present study, has a slightly lower trait frequency than the 41.7% reported here. The discrepancy between these figures may be a reflection of inter-observer error rather than of a biologically based difference. Saunders (1978) reports a frequency of only 13% for *lumbosacral transitional vertebra* in a combined Eskimo-Aleut skeletal sample, a substantially lower frequency than reported here.

Sex. Males had the trait almost two times more frequently than females (OR=1.84, lower and upper confidence limits 0.92 and 6.65 respectively). However, the odds ratio did not reach a significant level ($p=0.084$). Table 6 shows that of the four population samples only Blacks had a female preponderance of S_1 *lumbarization*, and here the difference was negligible (27.1% versus 31.7% for males and females, respectively). For the other three population groups the opposite was true, particularly so for Aleuts among whom the male frequency was double the female frequency (55.2% versus 24.1%).

Population*Sex Interaction term. When this term was added to the population + sex logit model, it was statistically significant ($p=0.014$). Only the Black male odds ratio approached significance with a probability value of 0.078. Clearly, the Black sample was causing the interaction, as the remaining three population groups had higher male than female frequencies.

Age. Main effect for age did not contribute to the final logit model. In both Eskimo and Aleut the young adults had a higher frequency of trait presence than the old adults, while the opposite was true for both the White and Black samples.

Evaluation. *S₁ lumbarization* is one of the most commonly occurring border shifting traits. It represent a caudal shift at the lumbosacral border. The logit model included both

population group and sex main effects in addition to a population*sex interaction term. Morphology of the area is established early during embryological development and it is likely that the significant population variability reflects a genetic basis for S_1 *lumbarization*. For the same reason, age stability among adults was expected and observed. Further research is required to corroborate the patterns suggested by these findings and perhaps to determine the reasons for the observed pattern of a generally higher male incidence.

The population*sex interaction was caused by the Black population group which showed a gender difference in the opposite direction from the other three samples. Specifically, the frequency of trait expression is greater in the Black female compared to the Black male group.

The strong performance of the population group term when added to the null or no effects model suggested S_1 *lumbarization* may be powerful for characterizing regional/racial groups, especially since it occurs with a fairly high frequency.

S₁ cleft neural arch

The logit model identified for this trait included main effects for population group and sex. The relationship between this bony trait and manifestation of genetically influenced spina bifida occulta involving a neural tube defect is unclear. Differences in the developmental timing of the two manifestations suggests that they may not be related (Barnes, 1994). In this study, S_1 *cleft neural arch* included defects presumably affecting only bone development.

Population. Only the frequency of trait present to trait absent in the Aleut sample, as compared to the White baseline, was significant with an odds ratio of 0.23 (lower and upper confidence limits of 0.09 and 0.61 respectively). Thus, Whites exhibited the trait almost four and a half times more frequently than Aleuts.

An examination of the frequency data also revealed that the largest difference characterized the White - Aleut comparison, the former having the highest frequency, at 14.1% and the latter having the lowest frequency, at 3.7%. The frequencies of the other samples fell within the range 9.1% (Black) to 12.7% (Late Woodland Amerind).

Again, because of a lack of consistent definitions and scoring protocol for spina bifida occulta, information that could be gleaned from the literature is not comparable.

Sex. According to the odds ratio for sex effect males had *S₁ cleft neural arch* slightly more than twice as frequently as females (OR=2.10, lower and upper confidence interval 1.39 and 3.16 respectively). This difference was highly significant (p=0.000). The males from each of the six population samples invariably showed a higher frequency of the feature than did the females.

Age. Though this term was not included in the final logit model it was interesting to compare frequency distribution between young and old adult cohorts. In the Kodiak Island sample the frequencies were almost equal by age cohort: 10.0% and 10.9% respectively. The trait was not observed in young Aleuts or young Whites in these samples, but occurred with a frequency of 3.9% and 14.6% in old Aleuts and old Whites respectively. In contrast, the other three population groups exhibited a higher frequency of the trait in the young versus the old cohorts.

Evaluation. This is a well known hypostotic congenital defect. Basically, *S₁ cleft neural arch* occurs during early embryological development as two sides of the neural arch fail to meet and fuse.

As for the population group term, it is generally accepted that congenital defects, particularly those manifest in the region of the spine, vary by population group. The fact that the population group term figured in the model was consistent with what is known about the nature of *S₁ cleft neural arch*. To the extent that population variability in this trait reflects genetic rather than environmental differences, it should be an ideal candidate for use in distance analysis, particularly because the sacrum fares well in terms of preservation compared to other regions of the skeleton and is thus relatively abundant in museum collections.

High sacral hiatus

The logit model for this trait included only a main effect for the population group variable. When the population group term was added to the null model, the probability value associated with the latter was highly significant ($p=0.000$).

Population. Only one of the five population group odds ratios was statistically significant ($p=0.006$). The frequency of trait presence to trait absence in the White compared to the Eskimo group was 1.00:4.48 (confidence interval of the odds ratio 1.53 to 13.08). Thus, Eskimos had the trait almost four and a half times more often than Whites. Kodiak Islanders approached statistical significance ($p=0.066$) in their odds ratio which was 3.35 (confidence limits 0.92 to 12.17 respectively). This sample had the trait over three times more frequently than the White sample.

Not surprisingly, Eskimos and Kodiak Islanders had the highest percentage frequency of the trait: 8.5% and 6.5%, respectively, compared to 2.0% in the White baseline sample which was the same as the frequency observed in the Black sample and slightly higher than the 1.0% frequency observed in the Late Woodland Amerind sample.

Though the level of the sacral hiatus has been reported in past studies (Stewart, 1932; Trotter and Letterman, 1944), there are no comparative population data available for abnormally high sacral hiati (i.e. at or above the 3rd sacral vertebra).

Age. For three samples the prevalence of high sacral hiatus tended to be higher in the young (Eskimo, Kodiak, Black), while for the other three (Aleut, Amerind, White) the tendency was for a higher prevalence in the old cohort.

Sex. None of the six populations listed in Table 6 showed more than a trivial difference between male and female subsample frequencies for this feature.

Evaluation. *High sacral hiatus* probably belongs in the hypostotic class of variability though its ultimate bony manifestation may be determined at a very early stage of axial skeleton development; i.e. during prenatal life through a variant of the sacral elements' primordia. The population group effect, when compared to the null or no effects model, is strong ($p=0.000$) suggesting that this trait would be a very valuable addition to the suite of vertebral traits used in the research of prehistoric population affinities.

Inter-trait Association

Twelve of the 78 inter-trait associations were statistically significant (Table 13), though only four would be expected by chance. Thus, though several of the twelve may

be random, at least some must be biologically based. As summarized by Saunders (1978) there are three main factors underlying the association between two traits:

- 1) Traits represent expressions of the same underlying variable, e.g., the association of double transverse foramen on contiguous cervical vertebrae.
- 2) Traits are associated through a generalized or localized developmental phenomenon such as retarded or arrested growth (hypostotic) or excess bony development (hyperostosis), e.g., the latter could produce an association between atlas lateral bridge and double transverse foramen of the sixth cervical vertebra.
- 3) Traits share a common regional, embryological or genetic origin, e.g., those representing caudal or cranial border shifts in axial segmentation.

With the exception of the atlas and axis transverse foramen defective traits, the initial research design excluded biologically redundant variants from the analysis, hence only the latter two categories were considered in interpreting the associations. Table 13 contains an inter-trait association matrix for 13 of the 14 traits, with phi association coefficients above the main diagonal and probability values under a null hypothesis of zero association below the main diagonal. The *S₁ lumbarization* trait was not included because, the data set associated with this trait was not comparable to the remaining data set.

Hyperostotic and hypostotic traits

Twelve traits whose morphology could be interpreted as manifestation of either delayed (arrested) or superfluous skeletal development were:

hypostotic

1. *Sternal aperture*
2. *Atlas transverse foramen defective*
3. *Axis transverse foramen defective*
4. *C₇ costal transverse foramen*
5. *S₁ cleft neural arch*
6. *High sacral hiatus*

hyperostotic

1. *Atlas bridge posterior*
2. *Atlas bridge lateral*
3. *C₆ double transverse foramen*
4. *Cervical rib*
5. *Lumbar rib*
6. *Six unit sacrum*

There were two features not included in this list. For one of these, *L₁ anticlinal unit*, there appeared to be no logical basis for assigning this trait to either of these classes. The other one, *S₁ lumbarization*, (not included in the phi analysis) conceivably could be interpreted as hypostotic.

Of the 66 phi coefficients generated by all pairwise tests of the features in the list, 30 followed the *direction* (positive or negative) predicted according to the hypostotic/hyperostotic dichotomy; 7 of these 30 were statistically significant values. The significant values involved 9 of 12 features as follows:

atlas bridge posterior - atlas bridge lateral

atlas bridge lateral - atlas transverse foramen defective

atlas bridge lateral - C₆ double transverse foramen

atlas transverse foramen defective - axis transverse foramen defective

C₆ double transverse foramen - high sacral hiatus

lumbar rib - six unit sacrum

six unit sacrum - high sacral hiatus

On the other hand, 34 of the 66 phi coefficients showed the *opposite direction* (positive or negative) from that predicted; and 4 of these were significant, involving 6 of the 12 features, as follows:

atlas bridge posterior - axis transverse foramen defective

atlas transverse foramen defective - C₇ costal transverse foramen

C₆ double transverse foramen - C₇ costal transverse foramen

six unit sacrum - S₁ cleft neural arch

In addition, 2 of the 66 phi coefficients had zero values.

Three traits which showed no significant phi value in support of their classification were *sternal aperture*, *cervical rib*, and surprisingly, *S₁ cleft neural arch*. Moreover, the latter had a contrary (positive phi) association with *six unit sacrum*, a trait classed as hyperostotic.

To complete this section, the pattern of phi coefficients for *L₁ anticlinal unit* was examined. Of the 12 generated by testing it against each trait listed above, 10 suggested *L₁ anticlinal unit* belongs to the hyperostotic category (phi for *atlas bridging lateral reaching significance*), while 2 showed the reverse.

On the whole, insufficient versus superfluous skeletal development appeared to be a weak explanatory variable for the expression of non-metric traits in the sternum and vertebral column.

Cranial/caudal border shifting

Seven of the features were interpreted as manifestations of border shifts of the axial segmentation in either the cranial or caudal direction. Shifts occur at all five borders:

occipitovertebral, cervicothoracic, thoracolumbar, lumbosacral and sacrococcygeal.

These traits were:

cranial shift

1. *Cervical rib*
2. *High sacral hiatus*

caudal shift

1. *Atlas bridge posterior*
2. *Atlas bridge lateral*
3. *L₁ anticlinal unit*
4. *Lumbar rib*
5. *Six unit sacrum*

A sixth caudal shift trait, *S₁ lumbarization*, was not tested. Six for which no known rationale existed to classify them either as cranial or caudal shift were: *sternal aperture*, *atlas transverse foramen defective*, *axis transverse foramen defective*, *C₆ double transverse foramen*, *C₇ costal transverse foramen* and *S₁ cleft neural arch*.

Of the 21 phi coefficients generated by all pairwise tests of the features in the list, 15 (71%) followed the direction predicted according to their border shift classification. Of these 15 phi values 4 were significant involving 6 of the traits, as follows:

atlas bridge posterior - atlas bridge lateral

atlas bridge lateral - L₁ anticlinal unit

lumbar rib - six unit sacrum

six unit sacrum - high sacral hiatus

Six of the 21 phi coefficients showed the opposite direction from that predicted, though none of these reached a statistically significant level.

Next, the 42 phi values for the six unclassified versus seven classified variants were examined. Two phi values were zero. The other 40 were tallied by cranial/caudal shift (Table 18). Of these 40 phi values, 13 indicated cranial shift association while 27 (68%) indicated caudal shift. As reinforcement for the latter, 4 of the 5 significant associations were in the caudal direction.

These findings raised certain intriguing questions which need to be addressed in future studies. *Sternal aperture* hitherto has been viewed unequivocally as belonging to the hypostotic class: Why then did only 3 of 11 (27%) coefficients support this, while 6 of 7 (86%) suggested instead that somehow this defect in the sternal body is associated with a caudal border shift of the vertebral column? Similarly, it is not likely that anyone would argue with the classification of *S₁ cleft neural arch* as representing arrested skeletal development; why in this case did only 4 of 10 (40%) phi values support its hypostotic classification, while 5 of 6 (83%), including a significant value for *six unit sacrum*, suggested instead that *S₁ cleft neural arch* is somehow related to caudal border shifting?

Also difficult to interpret were the apparent caudal shift associations of the C₆ and C₇ transverse foramen variants, which fit more satisfactorily than did their hypostotic/hyperostotic pattern of associations. Further, *C₆ double transverse foramen* and *C₇ costal transverse foramen* showed significant positive association with each other, a finding inconsistent with the classification of the former as hyper- and the latter as hypostotic. Their pattern suggested that these foraminal variants merit further research in order to determine the developmental relationships between foramina transversaria, caudal shift at the cervicothoracic border, and variants of the deep vasculature of the neck.

TABLE 18. Breakdown of phi values by non-classified versus classified cranial/caudal border shift traits.

Trait	Shift		Trait giving significant phi value
	Cranial	Caudal	
<i>Sternal aperture</i>	1	6	
<i>Atlas transverse foramen defective</i>	4 *	3	atlas bridge lateral
<i>Axis transverse foramen defective</i>	3	4 *	atlas bridge posterior
<i>C₆ double transverse foramen</i>	2	4 **	atlas bridge lateral, high sacral hiatus
<i>C₇ costal transverse foramen</i>	2	5	
<i>S₁ cleft neural arch</i>	1	5 *	six unit sacrum

* The number of asterisks indicates the number of significant phi associations.

To conclude this section: Clearly it was worthwhile examining, not just the statistically significant values, but the entire matrix of phi coefficients in an attempt to discern patterns which might shed light on the etiology and morphological significance of the traits. According to the tallies, border shifting figured prominently as an explanatory variable for the expression of non-metric traits of the infracranial axial skeleton. Further, the tendency for caudal shift predominated over that for cranial shift. This was consistent with the general evolutionary trend thought to characterize our species (Barnes, 1994:81).

Distance Analysis

Cluster analysis

The most striking similarity between the dendrogram based on Mahalanobis distances (Figure 13) and the one based on MMDs (Figure 14) is that Blacks and Whites are closely linked together, and not at all closely related to the major cluster containing the 10 American indigenous groups (Amerind).

As well, there are similarities between the diagrams with respect to relationships among the Amerinds. Firstly, Illinois Hopewell and Plains are the most tightly linked pair. Secondly, in each diagram the Hopewell-Plains pair is joined stepwise by Alaskan Eskimo, then by Kodiak in one subcluster. Thirdly, both dendrograms place Athabascans with Aleut and Inupiaq Eskimo together in a second subcluster.

On the other hand the Mahalanobis and MMD-derived dendrograms differ with respect to placement of certain groups in the Amerind major cluster. Notably, Late Woodland is closely linked to Kodiak in the MMD dendrogram; but in the Mahalanobis dendrogram it straggles into the Amerind cluster by itself, the last of the 10 to join.

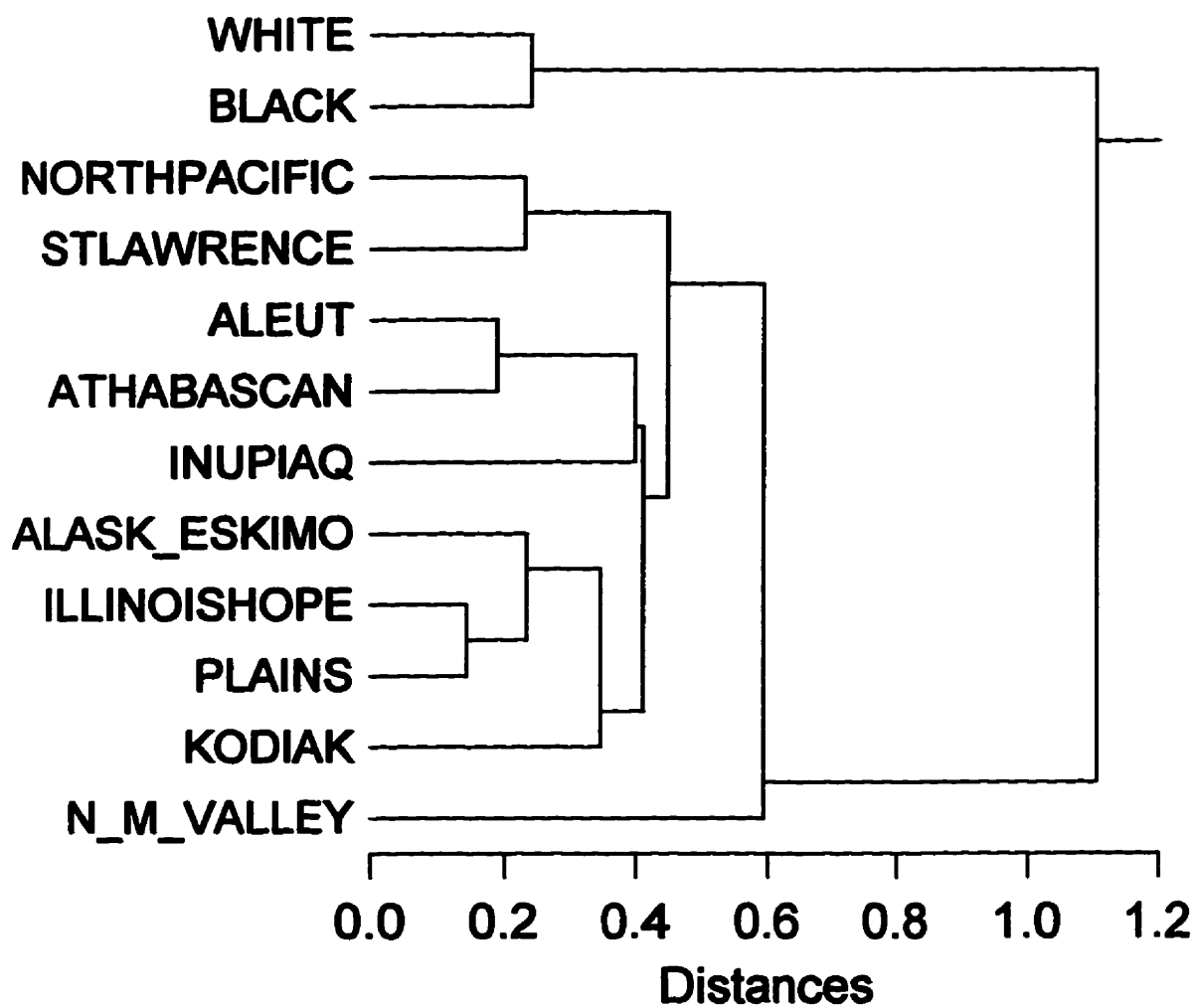


FIGURE 13. Dendrogram for Mahalanobis distances based on 10 non-metric traits of the vertebral column.

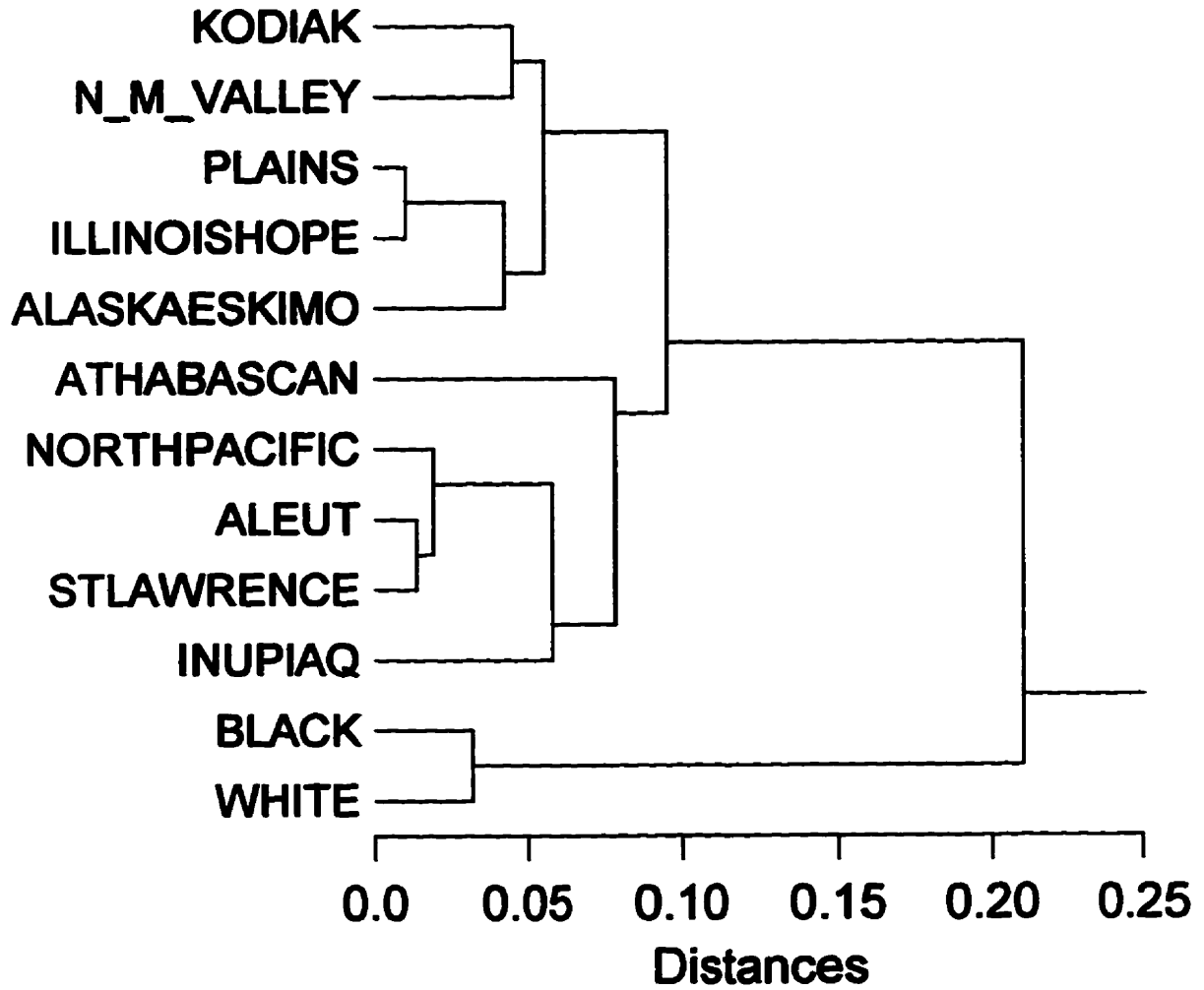


FIGURE 14. Dendrogram for MMD distances based on 10 non-metric traits of the vertebral column.

Multidimensional scaling

Figures 15 and 16 are two-dimensional plots of the 12 populations produced by multidimensional scaling based on Mahalanobis distances and MMDs, respectively. Again, both MDS plots are similar in placing White and Black samples at the periphery and somewhat apart from the 10 Amerind groups. However, the separation is not as unequivocal here as in the dendrogram; for example in Figure 16, Blacks are as close to Athabascans as to Whites, and reciprocally, Athabascans are closer to Blacks than to certain Amerind groups.

Plains and Hopewell are very close in both diagrams. As in the dendrograms there is not a tendency for all Eskimos to cluster together and apart from Indians. Aside from that, the specific relationships among the Amerind groups are different in the two MDS plots. The Mahalanobis plot shows a tight central grouping including Hopewell, Plains, Inupiaq and Saint Lawrence. Arranged around this cluster are the other Amerinds, clockwise from above left: Athabascans, Aleuts, Late Woodland Amerind, Kodiak Island, South Alaskan Eskimo and North Pacific Coast Amerind. In the MMD plot Saint Lawrence-Aleut are as close to each other as are Hopewell-Plains, but the other groups are somewhat isolated.

Both MDS plots are characterized by shallower dispersion along the y (Dimension -2) than along the x (Dimension -1) axis, with the range of population points along the x axis somewhat broader in the Mahalanobis than in the MMD plot (-2.5 to +1.5 versus -1.5 to +2.0, respectively).

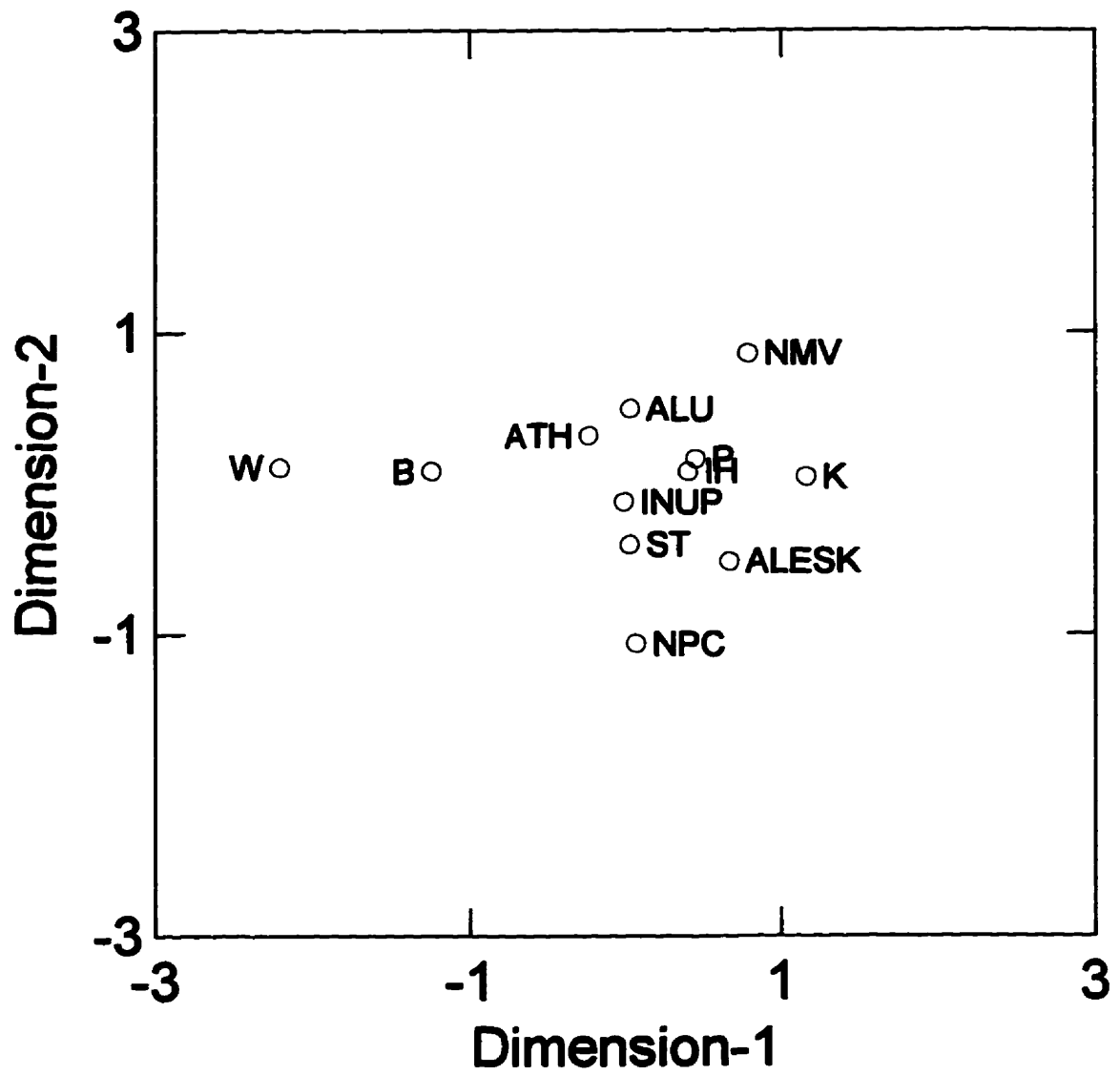


FIGURE 15. MDS scatterplot for Mahalanobis distances based on 10 non-metric traits of the vertebral column.

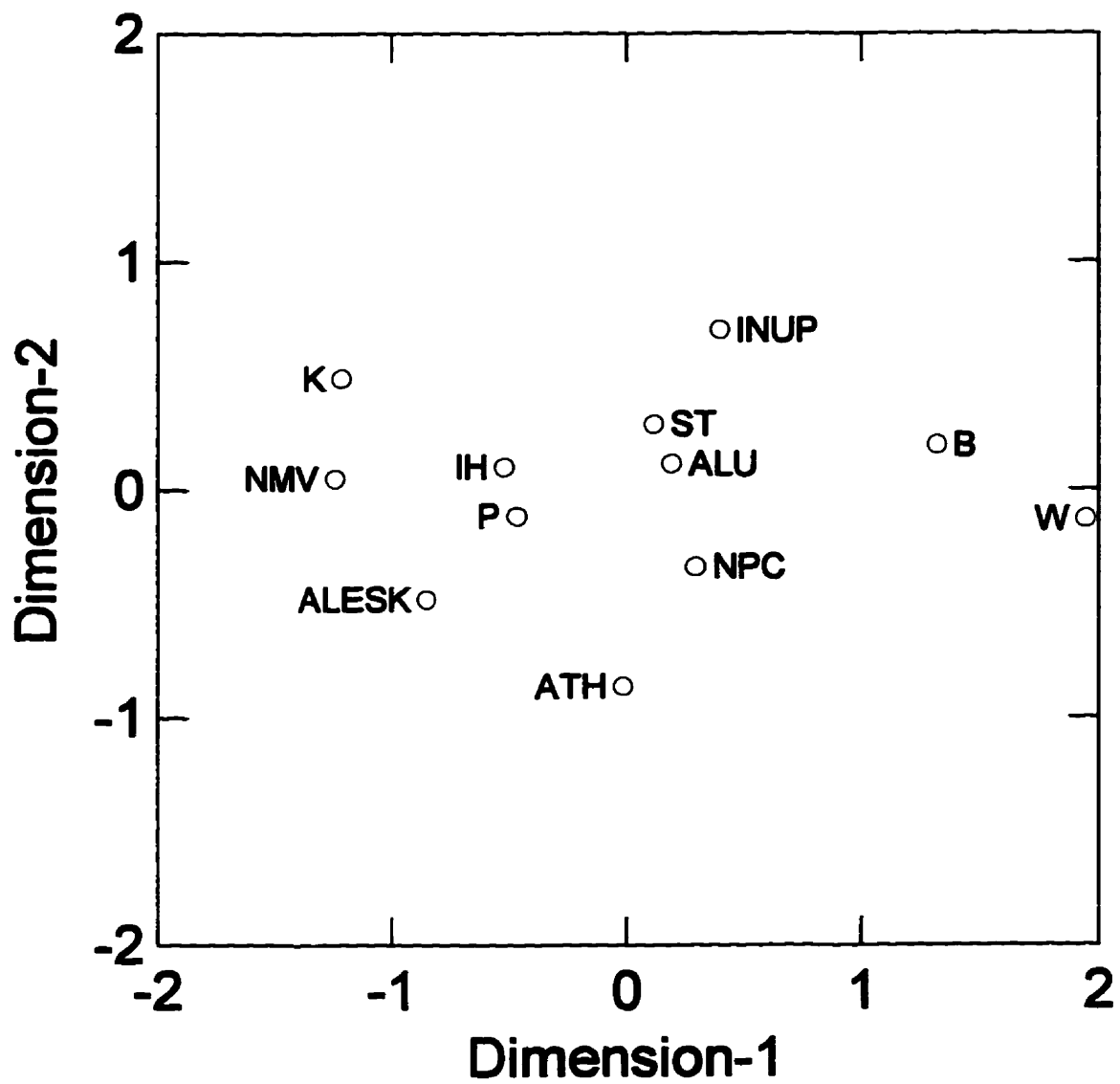


FIGURE 16. MDS scatterplot for MMD distances based on 10 non-metric traits of the vertebral column.

Ethnogenesis

The three-wave hypothesis of peopling of the New World (Greenberg et al., 1986) states that the first migration wave was comprised of ancestors of North American Indians, the second brought ancestors of the Na-Dene, and the most recent was comprised of ancestors of Aleuts and Eskimos. This hypothetical pattern of migration is not supported by the data presented here. The dendrogram (Figure 13) did not form three distinct clusters representing the three “waves”. Of the two Na-Dene samples, one (North Pacific Coast Indian) is linked with Yupik Eskimo (Saint Lawrence) and one (Athabascan) is linked with Aleut. In addition, each of the three Eskimo groups (Saint Lawrence, South Alaskan Eskimo and Arctic/Inupiaq Eskimo) joins preferentially to Indians before eventually joining each other. Aleuts and Eskimos are not more closely joined to each other than either is to Indians.

The MDS graph also failed to support the three-migration hypothesis (Figure 15). As in the dendrogram, the Athabascan and North Pacific Coast Indian are not near to one another. Aleut are closer to Athabascan, Late Woodland and Plains than to any Eskimo sample. Three Eskimo groups are in the same vicinity (Arctic/Inupiaq, Saint Lawrence and South Alaskan Eskimo). Nevertheless, Hopewell-Plains intervene in position between the Eskimo cluster and the Aleut sample.

Based on a variety of physical anthropological evidence several workers dispute a three-migration ethnogenesis model for the indigenous New World (Merriwether et al., 1995; Ossenberg, 1992, 1994; Ousley, 1995). According to cranial non-metric

frequencies representing several northwestern North American populations, early and recent, Ossenberg (1992, 1994) shows that Aleuts were more closely related to Athabascans, Late Woodland and Plains than to Eskimos; reciprocally, Eskimos were closer to Athabascans than to Aleuts. She proposes a scenario for the peopling of the American Northwest which, as does the three-wave hypothesis (Greenberg et al., 1986), sees two founding groups. However, she disputes this hypothesis in suggesting that one group ("Paleoartic") was ancestral to Na-Dene speakers *and* Aleut, the more recent ("Neoartic") ancestral to Eskimo. The Eskimo-Athabaskan affinity is explained as the result of demic diffusion as the Neartic arrivals advanced into Alaska where they encountered, and mixed with, Paleoartic descendent peoples occupying these territories. This process of demic diffusion, however, did not advance into the Aleutian archipelago; here, the Aleuts were geographically isolated, surviving as a relic Paleoartic group up to the time of Russian contact in the 18th century.

This pattern of migration is partially supported by the data presented here.

Ossenberg's cranial MMD dendrograms consistently link the Aleut with Na-Dene and then Plains Indian. Of her Na-Dene samples, the northern Athabaskan sample (Ingalik) is contained within the Aleut cluster. The Mahalanobis based dendrogram (Figure 13) links Aleut with Athabaskan at a level slightly higher than that which the two closest population groups were linked. The other Na-Dene population group, North Pacific Coast Indian, joins directly with the Saint Lawrence Island Eskimo group, and the newly formed cluster does not join with the Aleut-Athabaskan cluster until the former joins with all other indigenous population groups, except for Late Woodland. The Aleut-Athabaskan cluster

eventually joins with the cluster that contains Plains Indians but not until after it is joined by Arctic/Inupiaq Eskimo.

The Mahalanobis MDS diagram places the Aleut closest to the Athabascan group and approximately equidistant from the Plains Indian group and the Arctic/Inupiaq Eskimo group. In addition, Aleut are fairly close to Late Woodland. North Pacific Coast is approximately equidistant from both South Alaskan Eskimo and Saint Lawrence Island Eskimo, and closer to these than to any other Indian population.

The relationships among the Hopewell, Late Woodland and Plains are not consistent with those reported by Ossenberg (1974; 1994). Her cranial data consistently link Late Woodland with Plains but place Illinois Hopewell elsewhere. She suggests that Illinois Hopewell were not in the Late Woodland-Plains ancestral lineage. Disputing this, the current data consistently placed the Illinois Hopewell Indian group with the Plains Indian group, at the lowest level of distance, but linked the Late Woodland with the cluster containing all other indigenous groups. This pattern would be more consistent with a reconstruction whereby Illinois Hopewell were ancestral to the Plains but not to the Late Woodland Indians of the northeastern Plains periphery.

The most striking feature of both the dendrogram and the MDS plot based on the Mahalanobis distances for vertebral variants is that the relationships depicted fail to support the long-standing assumption of an intimate Aleut-Eskimo biological affinity. It appears that neither the Aleut or Eskimo are closer to each other than either is to Indian. The Aleut group joins first with an Indian group (Athabascan) and is then joined by an Eskimo group (Arctic/Inupiaq). The three Eskimo groups all join first with an Indian

group before eventually joining to the Aleut-Athabascan cluster. In the MDS graph the Arctic/Inupiaq Eskimo and Saint Lawrence Island Eskimo are in close proximity but the former is even closer to the Illinois Hopewell-Plains Indian groups. The South Alaskan Eskimo group is closest to Saint Lawrence Island Eskimo but is also close to North Pacific Coast Indian.

Forensic applications

It was interesting to examine the patterns of trait frequencies among the three “racial” groups (European-White, African-Black, Asian-derived). Without taking into account size or statistical significance of frequency differences, we may note from Table 19 that Blacks have an intermediate frequency for 9 of the 14 vertebral variants, or approximately double the number that would be expected by chance. However, for most of these “Black-intermediate” features the Black percentage was only *marginally* intermediate. In fact, the only ones for which their percentage was symmetrically intermediate were *lumbar rib* and *S₁ lumbarization*. For 9 of the 14 traits the Blacks were closer to Whites than to Amerinds, and for four of these the affinity was striking: *atlas bridge lateral*, *C₇ costal transverse foramen*, *six unit sacrum*, and especially, *L₁ anticlinal unit*. It seems that these four features would prove powerful for discriminating Amerindian remains from those of either American Blacks or Whites. Of these, *L₁ anticlinal unit* stood out as highly discriminatory: 51% in Amerinds versus 7% in Blacks and 1.5% in Whites. *High sacral hiatus* (2% in Blacks and Whites versus 6% in Amerinds) might also be included in this potential suite of discriminators.

TABLE 19. Mean percentage frequency for 14 traits, by three major "racial" groups.

Racial group	<i>Sternal aperture</i>	<i>Atlas bridge posterior</i>	<i>Atlas bridge lateral</i>	<i>Atlas transverse foramen defective</i>	<i>Axis transverse foramen defective</i>	<i>C₆ double transverse foramen</i>	<i>Costal transverse foramen</i>
White	4.0	5.0	0.5	6.2	1.0	39.2	4.6
Black	8.7	11.2	1.5	9.2	3.1	33.5	4.8
Asian-derived	3.5	11.9	10.6	3.7	3.6	43.3	13.8

Racial group	<i>Cervical rib</i>	<i>L₁ anticlinal unit</i>	<i>Lumbar rib</i>	<i>Six unit sacrum</i>	<i>S₁ lumbarization¹</i>	<i>S₁ cleft neural arch</i>	<i>High sacral hiatus</i>
White	1.1	1.5	8.8	48.4	21.8	14.1	2.0
Black	1.6	7.1	12.4	43.4	29.4	9.1	2.0
Asian-derived	5.9	51.3	14.8	30.4	41.2	10.3	6.1

¹ Asian-derived represented by data for Aleut and Eskimo only, scored by the author.

In the case where a forensic investigator had to determine whether skeletal remains were those of a Black or White American, a potential battery might include: *sternal aperture*, *atlas bridge posterior*, *L₁ anticlinal unit*, *lumbar rib*, *S₁ cleft neural arch*, and *S₁ lumbarization* (Table 19). Because none of these features show marked frequency differences between Black and White, however, the answer to this particular query would not likely stand as unequivocally in a court of law (with a high level of statistical probability) as would the answer to the question concerning whether remains were of a Native American versus Black or White.

In any case, more research is needed to amass a large definitive database for comparative purposes, and to refine statistical techniques for use of the vertebral traits in forensic investigations.

CHAPTER VI: SUMMARY AND CONCLUSIONS

Logit analysis is an appropriate statistical method for analyzing the effects of population, age and sex on the distribution of non-metric skeletal variants. Using six large aggregate skeletal samples, two age groups (young and older adult) and two sexes, a logit model was created for 14 traits of the sternum and vertebral column. Of the 14 logit models 11 contained the population term, supporting the assumption of a genetic basis for trait expression. Four also contained the age term; of these, two contained the population*age interaction term. The remaining three contained the sex term in addition to the population term; of these, one contained the population*sex interaction term. One trait contained the age and sex terms, one trait contained just the sex term and one trait contained no main effects terms.

Inclusion of the population term in the final logit model supported the assumption that there is a genetic component to trait expression. Based on the probability value associated with the population group term, the importance of this term to the model could be quantified. Of the eleven traits that contained the population group term in their logit model, the probability values associated with this term ranged from 0.000 for *atlas bridge posterior*, *atlas bridge lateral*, *C₇ costal transverse foramen*, *L₁ anticlinal unit*, *six unit sacrum*, *S₁ lumbarization*, and *high sacral hiatus*, to 0.052 for *C₆ double transverse foramen*. This information can be used to create a customized trait list, specifically tailored for distance analysis studies, consisting of those traits whose population term indicated the relatively important genetic component of trait expression.

Of the 78 phi coefficients 12 indicated a statistically significant inter-trait association. Only four would be expected by chance. Of the 66 phi coefficients generated by all pairwise tests of the 12 traits classified as hypostotic or hyperostotic, 30 followed the direction (positive or negative) predicted and seven of these were statistically significant. Of the 21 phi coefficients generated by all pairwise tests of the seven traits classified as cranial or caudal border shift, 15 followed the direction predicted and four of these were statistically significant. In addition, 42 phi coefficients were generated by comparing the six traits that could not be classified as cranial or caudal border shift with the seven that were. Twenty-seven (68%) indicated association with caudal shift and 13 (32%) indicated association with cranial shift. The pattern of association for both *sternal aperture* and *S₁ cleft neural arch*, traditionally classified as hypostotic, seemed to suggest that both were somehow related to caudal border shifting. Also difficult to interpret were the apparent caudal shift associations of the *C₆* and *C₇* transverse foramen variants, which fit more satisfactorily than did their hypostotic/hyperostotic pattern of associations. Further, *C₆ double transverse foramen* and *C₇ costal transverse foramen* showed significant positive association with each other, a finding inconsistent with the classification of the former as hyperostotic and the latter as hypostotic. Their pattern suggested that these foraminal variants merit further research in order to determine the developmental relationships between foramina transversaria, caudal shift at the cervicothoracic border, and variants of the deep vasculature of the neck.

The use of logit analysis and inter-trait association data in conjunction with the Mahalanobis D^2 distance statistic, as a means of determining relative biological distances

between prehistoric populations, was successful. Logit modeling produced “threshold values” for each trait, by population. The logit or threshold value was the *age-and-sex adjusted* log odds of trait presence for each population group, and was considered the median of a logistically distributed trait propensity variable, over all individuals from a specific population group. The inter-trait association matrix took into account inter-trait associations in the final distance calculations. Therefore, traits that were associated but revealed a strong population/genetic component in their logit model, did not have to be removed from the distance analysis.

Ten non-metric traits were used for the calculation of Mahalanobis D^2 distances, and these were compared to distances obtained using the same 10 non-metric traits in conjunction with the Smith’s Mean Measure of Divergence statistic. The comparison was based on Spearman’s rank-order correlation coefficient, which was highly significant, and visual inspection of the Mahalanobis D^2 and MMD based cluster dendrograms and Mahalanobis D^2 and MMD based MDS scatterplots. In both the dendrogram and the MDS diagram, the most obvious similarity was the clustering of the Black and White samples at a relatively low level, and their subsequent linking to the cluster containing all other indigenous population groups, at highest level. Using both distance methods the Black-White cluster was the last to join and the Illinois Hopewell and Plains Indians cluster was the first to join. In addition, both dendrograms indicated that the North American indigenous groups form two distinct subclusters. The first cluster contained Athabascan, North Pacific Coast Indian, Aleut, Saint Lawrence Island and Arctic/Inupiaq Eskimo. The second cluster contained South Alaskan Eskimo, Illinois Hopewell Indian,

Plains Indian and Kodiak Island in the MMD based dendrogram and all of the former in addition to Late Woodland Amerind in the Mahalanobis D^2 based dendrogram.

Within the context of ethnogenesis research, the dendrogram and MDS plot created from the Mahalanobis D^2 distance calculations did not support the three-wave hypothesis of peopling of the New World (Greenberg et.al., 1986). To be consistent with this hypothesis it was expected that three clusters would be apparent: Aleut-Eskimo, Na-Dene Indian, and North American Indian. Instead, one of the two Na-Dene groups linked closely with Eskimo and the other Na-Dene group linked closely with Aleut. In addition, one of the three Eskimo groups linked with the Illinois Hopewell-Plains cluster, another linked with the Aleut-Athabaskan cluster, and the third linked closely with Na-Dene Indian. The pattern of cluster analysis observed in the present study supports Ossenbergs' (1992, 1994) hypothesis that the second wave consisted of ancestors of Aleut-Na-Dene Indians and the third wave consisted of ancestors of the Eskimo. In summary, neither the Aleuts or Eskimos were more closely related to each other than either was to American Indians.

Finally, the potential for forensic applications, of at least some of the non-metric traits of the vertebral column, is promising. In univariate comparisons of trait frequencies, several exhibited substantial discrepancies between Blacks and Whites on the one hand, and Asian-derived (North American Indigenous) groups on the other hand. No traits were useful for discriminating between the Black and White population group. Further statistical analyses are required to assess the accuracy and ability of these traits to discriminate, in a forensics situation, among these three "racial" groups.

Fourteen traits that were predicted to perform well were selected for analysis. The chosen traits possessed a series of desirable characteristics:

- 1) They are easy to score consistently and therefore have high intra/inter-agreement.**
- 2) They occur in frequencies high enough to be amenable to multivariate statistical analysis.**
- 3) They are not functionally or behaviourally influenced.**
- 4) They are not biologically redundant expressions of the same thing.**

It has been argued that the reason non-metric traits have not performed well has been as a result of lack of diligence in choosing the traits. This study proves that non-metric traits in general, and non-metric traits of the vertebral column in particular, are useful for studying affinities of prehistoric populations. In particular, this study rectifies the previous neglect of non-metric traits of the vertebral column as a tool for studying biological relationships and clearly shows that non-metric traits of the vertebral column have as much potential as those of the cranium for this type of research.

REFERENCES

- Abitol MM (1987) Evolution of the sacrum in Hominoids. *American Journal of Physical Anthropology* 74:65-81.
- Agresti A (1996) *An Introduction to Categorical Data Analysis*. New York, John Wiley & Sons, Inc..
- Aiello L and C Dean (1990) *An Introduction to Human Evolutionary Anatomy*. New York, Academic Press.
- Anderson JE (1963) *The People of Fairity: An Osteological analysis of an Iroquois Ossuary*. National Museum of Canada, Bulletin No. 193, Contributions to Anthropology pp. 29-129.
- Anderson JE (1968) Skeletal anomalies as genetic indicators. In Brothwell DR (ed.): *The skeletal biology of earlier human populations*. Toronto, Pergamon Press, pp. 135-147.
- Ashley GT (1956) The relationship between the pattern of ossification and the definitive shape of the mesosternum in man. *Journal of Anatomy* 90:87-105.
- Beatton M and NS Ossenberg (1996) Cortical defects at muscle attachment sites of the upper humerus shaft: patterns of age, sex, and subsistence variation in Aboriginal North America. Paper presented at the 24th annual meeting of the Canadian Association for Physical Anthropology, Kingston, Ontario, October 30-November 2, 1996.
- Barnes E (1994) *Developmental Defects of the Axial Skeleton in Paleopathology*. Colorado, University Press of Colorado.
- Benfer RA (1970) Associations among cranial traits. *American Journal of Physical Anthropology* 32:463-464.
- Berry RJ (1963) Epigenetic polymorphism in wild populations of *Mus musculus*. *Genetical Research* 4:193-220.
- Berry AC (1975) Factors affecting the incidence of non-metrical skeletal variants. *Journal of Anatomy* 120:519-535.
- Berry AC and RJ Berry (1967) Epigenetic variation in the human cranium. *Journal of Anatomy* 101:361-379.
- Berry AC, Berry RJ, and PJ Ucko (1967) Genetical changes in ancient Egypt. *Man* 2:551-568.

- Birkby WH (1973) Discontinuous Non-metric Traits of the Skull as Population Markers in the Prehistoric Southwest. Ph.D. Dissertation, University of Arizona.**
- Bishop YM, Fienberg SE, and PW Holland (1975) Discrete Multivariate Analysis: Theory and Practice. Cambridge, MIT Press.**
- Blangero J and S Williams-Blangero (1991) Estimating biological distance from dichotomous threshold traits. American Journal of Physical Anthropology 12:51-52 (abstract).**
- Blangero J and S Williams-Blangero (1993) A quantitative genetic method for calculating genetic distances from dermatoglyphic pattern types. American Journal of Physical Anthropology 16:57-58 (abstract).**
- Bornstein PE and RR Peterson (1966) Numerical variation of the presacral vertebral column in three groups in North America. American Journal of Physical Anthropology 25:139-146.**
- Bradt Miller B (1984) Congenital anomalies of the lower spine in two Arikara skeletal series. Plains Anthropologist 29:327-333.**
- Bray TL and TW Killion (1994) Reckoning with the Dead: The Larsen Bay Repatriation and the Smithsonian Institution. Washington, Smithsonian Institution Press.**
- Brothwell DR (1959) The use of non-metrical characters of the skull in differentiating populations. Ber. 6 Tag. Dtsch. Ges Anthropol. Kiel 103:103-109.**
- Buikstra JE (1972) Hopewell in the Lower Illinois Valley. Ph.D. Dissertation, University of Chicago.**
- Cadien JD, Harris EF, Jones WP, and LJ Mandarino (1976) Biological lineages, skeletal populations, and microevolution. Yearbook of Physical Anthropology 18:194-201.**
- Colgan PW and JT Smith (1978) Multidimensional contingency table analysis. In Colgan PW (ed.): Quantitative Ethology. Toronto, John Wiley and Sons.**
- Constandse-Westermann TS (1972) Coefficients of Biological Distance. Oosterhout, Anthropological Publications.**
- Cooper PD, Stewart JH, and WF McCormick (1988) Development and morphology of the sternal foramen. The American Journal of Forensic Medicine and Pathology 9:342-347.**

- Corruccini RS (1974) An examination of the meaning of cranial traits for human skeletal biology studies. American Journal of Physical Anthropology 40:425-446.**
- Craigmile TK (1977) Congenital anomalies of the spine. In Ruge D and LL Wiltse (eds): Spinal Disorders: Diagnosis and Treatment. Philadelphia, Lea & Febiger.**
- Cybulski JS (1992) A Greenville Burial Ground: Human Remains and Mortuary Elements in British Columbia Coast Prehistory. Archaeological Survey of Canada, Mercury Series Paper No. 146, Canadian Museum of Civilization.**
- Cybulski JS (1996) Context of Human Remains from the Lachane site, GbTo 33. Manuscript on file, Library Documents Section (Archaeology), Canadian Museum of Civilization.**
- de Beer Kaufman P (1974) Variation in the number of presacral vertebrae in Bantu-speaking South African Negroes. American Journal of Physical Anthropology 40:369-374.**
- Deol MS and GM Truslove (1957) Genetical studies on the skeleton of the mouse XX. Maternal physiology and variation in the skeleton of C57BL mice. Journal of Genetics 55:288-312.**
- De Stephano GF, Hauser G, Guidotti A, Rossi S, Gualdi Russo E, and P Brasili Gualandi (1984) Reflections on interobserver differences in scoring nonmetric cranial traits (with practical examples). Journal of Human Evolution 13:349-355.**
- Dumond DE and Scott GR (1991) The Uyak Site on Kodiak Island: Its Place in Alaskan Prehistory. Eugene: Oregon State Museum of Anthropology, and Department of Anthropology, University of Oregon.**
- Epstein BS (1976) The Spine: A Radiological Text and Atlas. Philadelphia, Lea and Febiger.**
- Finnegan M (1972) Population Definition on the Northwest coast by Analysis of Discrete Character Variation. Ph.D. Dissertation, University of Colorado.**
- Finnegan M (1978) Non-metric variation of the infracranial skeleton. Journal of Anatomy 125:23-37.**
- Finnegan M and K Cooprider (1978) Empirical comparison of distance equations using discrete traits. American Journal of Physical Anthropology 49:39-46.**
- Gaherty GG (1970) Skeletal Variation in Seven African Populations. Ph.D. Dissertation, University of Toronto.**

- Gardner RJM, Alexander C, and AMO Veale (1974) Spina bifida occulta in the parents of offspring with neural tube defects. *Journal de Genetique Humaine* 22:389-395.
- Green RF and JM Suchey (1976) The use of inverse sine transformations in the analysis of non-metric cranial data. *American Journal of Physical Anthropology* 45:61-68.
- Green RF, Suchey JM, and DV Gokhale (1979) The statistical treatment of correlated bilateral traits in the analysis of cranial material. *American Journal of Physical Anthropology* 50:629-634.
- Greenberg JH, Turner CG, and SL Zegura (1986) The settlement of the Americas: A comparison of linguistics, dental and genetic evidence. *Current Anthropology* 27:477-488.
- Grewal MS (1962) The rate of genetic divergence of sublines in the C57BL strain of mice. *Genetic Research* 3:226-237.
- Gruneberg H (1952) Genetical studies on the skeleton of the mouse IV. Quasi-continuous variations. *Journal of Genetics* 51:95-114.
- Heathcote GM (1986) *Exploratory Human Craniometry of Recent Eskaleutian Regional Groups from the Western Arctic and Subarctic of North America*. Oxford, BAR International Series.
- Hertzog KP (1968) Associations between discontinuous cranial traits. *American Journal of Physical Anthropology* 29:397-403.
- Honeij JA (1920) Cervical ribs. *Journal of Surgery, Gynecology and Obstetrics* 30:481-493.
- Howe WL and PA Parsons (1967) Genotype and environment in the determination of minor skeletal variants and body weight in mice. *Journal of Embryology and Experimental Morphology* 17:283-292.
- Jackes M (1977) *The Huron Spine: A Study Based on the Kleinberg Ossuary Vertebrae*. Ph.D. Dissertation, University of Toronto.
- James CCM and LP Lassman (1962) Spinal dysraphism: The diagnosis and treatment of progressive lesions in spina bifida occulta. *The Journal of Bone and Joint Surgery* 44B:828-840.
- Jantz RL (1970) *Change and Variation in Skeletal Populations of Arikara Indians*. Ph.D. dissertation, University of Kansas.

- Johnson RA and DW Wichern (1988) Applied Multivariate Statistical Analysis. Second edition. New Jersey, Prentice Hall.**
- Kachigan SK (1991) Multivariate Statistical Analysis: A Conceptual Introduction. Second edition. New York, Radius Press.**
- Kaufman L and PJ Rousseeuw (1990) Finding Groups in Data: An Introduction to Cluster Analysis. Toronto, John Wiley and Sons, Inc..**
- Kellock WL and PA Parsons (1970a) Variation of minor non-metrical skeletal variants in Australian Aborigines. American Journal of Physical Anthropology 32:409-421.**
- Kellock WL and PA Parsons (1970b) A comparison of the incidence of minor nonmetrical cranial variants in Australian Aborigines with those of Melanesia and Polynesia. American Journal of Physical Anthropology 33:235-240.**
- Kohler A and EA Zimmer (1968) Borderlands of the Normal and Early Pathologic in Skeletal Roentgenology. New York, Grune and Stratton.**
- Konigsberg LW (1987) Population Genetic Models for Interpreting Prehistoric Intra-cemetery Biological Variation. Ph.D. Dissertation, Northwestern University.**
- Konigsberg LW, Kohn LAP, and JM Cheverud (1993) Cranial deformation and nonmetric trait variation. American Journal of Physical Anthropology 90:35-48.**
- Korey KA (1970) Characteristics of the Distribution of Non-metric Variants of the Skull. M.A. Thesis, University of Chicago.**
- Korey KA (1980) The incidence of bilateral nonmetric skeletal traits: A reanalysis of sampling procedures. American Journal of Physical Anthropology 53:19-23.**
- Kruskal JB (1964) Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychometrika 29(1) 1-27.**
- Kuhne K (1932) Die verebung der variationen der menschlichen wirbelsale. Zeitschrift fur Morphologie und Anthropologie 30:1-221.**
- Kuhne K (1934) Symmetrieverhaltnisse und die absbrietungszentren in der variabilitat der regionalen grenzen der wirbelsaule des menschen. Zeitschrift fur Morphologie und Anthropologie 34:191-206.**
- Kuhne K (1936) Die zwillings wirbelsaule. Zeitschrift fur Morphologie und Anthropologie 35:1-375.**

- Lane RA and AJ Sublett (1972) Osteology of social organization in a residence pattern. *American Anthropologist*. 37:186-201.
- Lanier RR (1939) The presacral vertebrae of American White and Black males. *American Journal of Physical Anthropology* 25:341-420.
- Laughlin WS and JB Jørgenson (1956) Isolate variation in Greenlandic Eskimo crania. *Acta Genetica* 6:3-12.
- Laurence KM, Bligh AS, and KT Evans (1968) Vertebral and other abnormalities in parents and sibs of cases of spina bifida cystica and of anencephaly. *Developmental Medicine and Child Neurology, Supplement* 16:107.
- Leck I (1984) The geographical distribution of neural tube defects and oral clefts. *British Medical Bulletin* 40:390-395.
- Le Double AF (1903) *Traite des Variations des Os du Crane de l'Homme*. Paris, Vigot Freres.
- Le Double AF (1912) *Traite des Variations de la Colonne Vertebrale de l'Homme*. Paris, Vigot Freres.
- Lilienfeld AM and DE Lilienfeld (1980) *Foundations of Epidemiology*. Second edition. New York, Oxford University Press.
- Lorber J and K Levick (1967) Spina bifida cystica: Incidence of spina bifida occulta in parents and controls. *Archives of Diseases of Childhood* 42:171-173.
- Ma L (1993) *Anomalous Bony Bridging of the Atlas: A Study of Variation According to Age, Sex and Population*. Manuscript on file, Department of Anatomy, Queen's University, Kingston, Ontario.
- MacDonald GF and RI Inglis (1981) An overview of the North Coast Prehistory Project (1966-1980) *BC Studies* 48:37-63.
- Mahalanobis PC (1936) On the generalized distance in Statistics. *Proc. Nat. Inst. Sc. (India)* 12:49-55.
- McCormick WF (1981) Sternal foramen in man. *The American Journal of Forensic Medicine and Pathology*. 2:249-252.
- McCormick WF and MM Nichols (1981) Formation and maturation of the human sternum. I. Fetal period. *The American Journal of Forensic Medicine and Pathology*. 2:323-328.

- McGrath JW, Cheverud JM, and JE Buikstra (1984) Genetic correlations between sides and heritability of asymmetry for nonmetric traits in Rhesus macaques on Cayo Santiago. *American Journal of Physical Anthropology* 64:401-411.**
- McMinn RMH and RT Hutchings (1985) Color Atlas of Human Anatomy. Chicago, Year Book Medical Publishers, Inc..**
- McWilliams KR (1974) Gran Quivera and Biological Distance in the U.S. Southwest. Ph.D. Dissertation, Arizona State University.**
- Merbs CM (1967) Human Burials of Silumiut, a Thule Culture site north of Chesterfield Inlet, Northwest Territories. Preliminary Report. Archaeological Survey of Canada, Museum of Man, National Museums of Canada. Manuscript No. 605.**
- Merbs CM (1974) The effects of cranial and caudal shift in the vertebral columns of northern populations. *Arctic Anthropology* XI-Supplement: 12-19.**
- Merbs CM (1983) Patterns of activity induced pathology in a Canadian Inuit population. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper No. 119.**
- Merchant V (1973) A Cross-sectional Growth Study of the Proto-historic Arikara from Skeletal Material Associated with the Mobridge site 939 (WWI), South Dakota. M.A. Thesis, The American University.**
- Merriwether DA, Rothhammer F, RE Ferrell (1995) Distribution of the four founding lineage haplotypes in Native Americans suggests a single wave of migration to the New World. *American Journal of Physical Anthropology* 98:411-430.**
- Mitchell GAG (1934) The lumbosacral junction. *The Journal of Bone and Joint Surgery* 16:233-254.**
- Molto JE (1979) The assessment and meaning of intraobserver error in population studies based on discontinuous cranial traits. *American Journal of Physical Anthropology* 51:333-344.**
- Molto JE (1983) Biological Relationships of Southern Ontario Woodland Peoples: The Evidence of Discontinuous Cranial Morphology. Ph.D. Dissertation, University of Toronto.**
- Muller TP and JT Mayhall (1971) Analysis of contingency table data on torus mandibularis using log linear model. *American Journal of Physical Anthropology* 34:149-154.**

- Ossenberg NS (1969) **Discontinuous Morphological Variation in the Human Cranium.** Ph.D. Dissertation, University of Toronto.
- Ossenberg NS (1974) **Origin and Relationships of Woodland Peoples: the Evidence of Cranial Morphology.** In *Aspects of Upper Great Lakes Anthropology: papers in Honor of Lloyd A. Wilfred*, edited by E. Johnson, pp. 15-39. Minnesota Prehistoric Archaeology Series No. 11. Minnesota Historical Society, St.Paul.
- Ossenberg NS (1976) **Within and between race distances in population studies based on discrete traits of the human skull.** *American Journal of Physical Anthropology* 45:701-716.
- Ossenberg NS (1977) **Congruence of distance matrices based on cranial discrete traits, cranial measurements, and linguistic-geographic criteria in five Alaskan populations.** *American Journal of Physical Anthropology* 47:93-98.
- Ossenberg NS (1981) **An argument for the use of total side frequencies of bilateral nonmetric skeletal traits in population distance analysis: The regression of symmetry on incidence.** *American Journal of Physical Anthropology* 54:471-479.
- Ossenberg NS (1992) **Native people of the American Northwest: Population history from the perspective of skull morphology.** In Takeru A, Aoki K, and T Kimura (eds.): *The Evolution and Dispersal of Modern Humans in Asia.* Japan, Hokusen-sha Publishing Company.
- Ossenberg NS (1994) **Origins and affinities of the Native Peoples of Northwestern North America: The evidence of cranial nonmetric traits.** In Bonnichsen R and DG Steele (eds.): *Method and Theory for Investigating the Peopling of the Americas.* Oregon, Center for the Study of the First American, Oregon State University. pp. 79-115.
- Ossenfort WF (1926) **The atlas in Whites and Negroes.** *American Journal of Physical Anthropology* 9:439-443.
- Ousley SD (1995) **Relationships between Eskimos, Amerindians, and Aleuts: Old data, new perspectives.** *Human Biology* 67:427-458.
- Paradox for Windows, version 5.0 (1994) Borland International Inc., Scotts Valley, California.
- Post RH (1966) **Pilot study: Population differences in the frequency of spina bifida occulta.** *Eugenics Quarterly* 13:341-352.
- Pyo J and RM Lowman (1959) **The "ponticulus posticus" of the first cervical vertebrae.** *Radiology* 72:850-854.

- Rao CR (1952) *Advanced Statistical Methods in Biometric Research*. New York, Chapman and Hall, Limited.
- Reynolds HT (1977) *The Analysis of Cross-classifications*. New York, The Free Press.
- Romanus T and A Tovi (1964) A variation of the atlas: roentgenologic incidence of a bridge over the groove on the atlas for the vertebral artery. *Acta Radiologica Diagnosis* 2:289-297.
- Russell F (1900) Studies in cranial variation. *American Naturalist* 34:737-747.
- Saluga G (1988) The incidence of spina bifida occulta in an historic and a modern London population. *Journal of Anatomy* 158:91-93.
- SAS System for Window, version 6.10 (1993) SAS Institute Inc., Cary, NC.
- Saunders SR (1978) The development and distribution of discontinuous morphological variation of the human infracranial skeleton. Ph.D Dissertation, University of Toronto.
- Saunders SR (1989) Nonmetric skeletal variation. In Iscan MY and KAR Kennedy (eds.): *Reconstruction of Life from the Skeleton*. New York, Alan R.Liss, Inc..
- Saunders SR and F Popovich (1978) A family study of two skeletal variants: Atlas bridging and clinoid bridging. 49:193-204.
- Sawin PB, Gow M, and M Muehlke (1967) Morphogenetic studies of the rabbit. XXXVII Genome Gradient Growth Pattern Malformations. *American Journal of Anatomy* 121:197-216.
- Searle AG (1954a) Genetical studies on the skeleton of the mouse. IX Causes of skeletal variation within pure lines. *Journal of Genetics* 52:68-102.
- Searle AG (1954b) Genetical studies on the skeleton of the mouse. XI The influence of diet on variation in pure lines. *Journal of Genetics* 52:68-102.
- Selby S, Garn SM and V Kanareff (1955) The incidence and familial nature of a bony bridge on the first cervical vertebra. *American Journal of Physical Anthropology* 13:129-141.
- Shmorl G and H Junghanns (1971) *The Human Spine in Health and Disease*. New York, Grune and Stratton.
- Siegel S and NJ Castellan (1988) *Nonparametric Statistics for the Behavioral Sciences*. Toronto, McGraw-Hill Book Company.

- Sjøvold T (1977) Non-metrical divergence between skeletal populations: the theoretical foundation and biological importance of C.A.B. Smith's Mean Measure of Divergence. *Ossa* 4, Suppl. 1.**
- Sneath PHA and RR Sokal (1973) Numerical Taxonomy: The Principles and Practice of Numerical Classification. San Francisco, W.H. Freeman and Company.**
- Spence MW (1974) Residential practices and the distribution of skeletal traits in Teotihuacan, Mexico. *Man* 9:262-273.**
- Steiner HA (1943) Roentgenologic manifestations and clinical symptoms of rib abnormalities. *Radiology* 40:175-178.**
- Stewart TD (1932) The vertebral column of the Eskimo. *American Journal of Physical Anthropology* 27:123-136.**
- Suchey JM (1975) Biological Distance of Prehistoric Central California Populations Derived from Non-metric Traits of the Cranium. Ph.D. Dissertation, University of California.**
- Systat 6.0 for Windows (1996) SPSS Inc., Chicago.**
- Taitz C and H Nathan (1986) Some observations on the posterior and lateral bridge of the atlas. *Acta Anatomica* 127:212-217.**
- Trinkaus E (1978) Bilateral asymmetry of human skeletal non-metric traits. *American Journal of Physical Anthropology* 49:315-318.**
- Trotter M and GS Letterman (1944) Variation in the female sacrum: Their significance in continued caudal anesthesia. *Journal of Surgery, Gynecology and Obstetrics* 78:419-424.**
- Truslove GM (1961) Genetical studies on the skeleton of the mouse. XXX A search for correlations between some minor variants. *Genetical Research* 2:431-438.**
- Tulsi RS (1972) Vertebral column of the Australian aborigine: selected morphological and metrical features. *Zeitschrift für Morphologie und Anthropologie* 64:117-144.**
- Tulsi RS (1975) The anatomy and radiology of the cervical vertebrae and tortuous vertebral artery. *Australasian Radiology* 19:258-264.**
- Utermohle CJ (1982) Cranial evidence for the migration of Thule Culture Eskimo into the Eastern Arctic. *American Journal of Physical Anthropology* 57:238.**

Utermohle CJ (1984) From Barrow Eastward: Cranial Variation of the Eastern Eskimo. Ph.D Dissertation, Arizona State University

Utermohle CJ and CM Merbs (1979) Population affinities of the Thule culture Eskimos in Northwest Hudson Bay. In McCartney AP (ed): Thule Eskimo Culture: An Anthropological Retrospective. Mercury Series, Archaeological Survey of Canada, Paper No. 88, pp.435-447.

Von Torklus D and W Gehle (1972) The upper cervical spine. New York, Grune and Stratton.

Willemsen E (1973) Understanding Statistical Reasoning. San Francisco, W.H. Freeman and Company.

Winder S (1981) Infracranial Nonmetric Variation: An Assessment of its Value for Biological Distance Analysis. Ph.D. Dissertation, Indiana University.

Wood-Jones F (1930-1931) The Non-metrical morphological characters of the skull as criteria for racial diagnosis. I, II, and III. Anatomy 65:179-195, 368-378, 438-445.

Wood-Jones F (1933-1934) The Non-metrical morphological characters of the skull as criteria for racial diagnosis. IV. Anatomy 68:96-108.

Zegura SL (1975) A multivariate analysis of the inter- and intra- population variation exhibited by Eskimo crania. Ph.D. Dissertation, University of Wisconsin.

APPENDICES

Appendix A. Logit model building sequence, by trait for the data set containing six population groups.

Sternal aperture

Model		Calculation of						
No.	Model terms	G ²	DF	Probability	difference statistic	Delta G ²	Delta DF	Delta Probability
1	Null (no effects)	26.52	23	0.277	-	-	-	-
2	Population	11.80	18	0.857	1 - 2	14.72	5	0.012
3	Age	25.69	22	0.260	1 - 3	0.83	1	0.362
4	Sex	25.80	22	0.260	1 - 4	0.72	1	0.396
5	Population + Age	11.29	17	0.841	2 - 5	0.51	1	0.475
6	Population + Sex	10.92	17	0.861	2 - 6	0.88	1	0.348

Atlas bridge posterior

Model		Calculation of						
No.	Model terms	G ²	DF	Probability	difference statistic	Delta G ²	Delta DF	Delta Probability
1	Null (no effects)	56.50	23	0.000	-	-	-	-
2	Population	33.36	18	0.015	1 - 2	23.14	5	0.000
3	Age	56.13	22	0.000	1 - 3	0.37	1	0.543
4	Sex	47.05	22	0.001	1 - 4	9.45	1	0.002
5	Population + Sex	25.74	17	0.079	2 - 5	7.62	1	0.006
6	Population + Age	33.27	17	0.010	2 - 6	0.09	1	0.764
7	Population + Sex + Pop*Sex	not enough data to test this model - standard errors unacceptably high						

Atlas bridge, lateral

Model		Calculation of difference						
No.	Model terms	G ²	DF	Probability	statistic	Delta G ²	Delta DF	Delta Probability
1	Null (no effects)	61.58	23	0.000	-	-	-	-
2	Population	19.63	18	0.354	1 - 2	41.95	5	0.000
3	Age	58.71	22	0.000	1 - 3	2.87	1	0.090
4	Sex	59.81	22	0.000	1 - 4	1.77	1	0.183
5	Population + Age	19.43	17	0.304	2 - 5	0.20	1	0.655

Atlas transverse foramen defective

Model		Calculation of difference						
No.	Model terms	G ²	DF	Probability	statistic	Delta G ²	Delta DF	Delta Probability
1	Null (no effects)	37.49	23	0.029	-	-	-	-
2	Population	25.05	18	0.124	1 - 2	12.44	5	0.029
3	Age	36.95	22	0.024	1 - 3	0.54	1	0.462
4	Sex	36.99	22	0.024	1 - 4	0.50	1	0.480
5	Population + Age	24.71	17	0.101	2 - 5	0.34	1	0.560
6	Population + Sex	24.27	17	0.112	2 - 6	0.78	1	0.377

Axis transverse foramen defective

Model No.	Model terms	Calculation of difference				
		G ²	DF	Probability	Delta statistic	Delta DF
1	Null (no effects)	26.50	23	0.278	-	-
2	Population	17.22	18	0.508	1-2	5
3	Age	24.47	22	0.323	1-3	1
4	Sex	26.13	22	0.246	1-4	1

C₆ double transverse foramen

Model No.	Model terms	Calculation of difference				
		G ²	DF	Probability	Delta statistic	Delta DF
1	Null (no effects)	33.55	23	0.080	-	-
2	Population	20.52	18	0.304	1-2	5
3	Age	27.66	22	0.187	1-3	1
4	Sex	30.02	22	0.118	1-4	1
5	Age + Population	16.67	17	0.477	3-5	5
6	Age + Sex	24.38	21	0.275	3-6	1
7	Age + Population + Sex	14.21	16	0.583	5-7	1
8	Age + Population + Age*Pop	10.56	12	0.567	5-8	5

C₇ costal transverse foramen

					Calculation of			
Model					difference	Delta	Delta	
No.	Model terms	G ²	DF	Probability	statistic	G ²	DF	Probability
1	Null (no effects)	52.54	23	0.000	-	-	-	-
2	Population	16.23	18	0.576	1 - 2	36.31	5	0.000
3	Age	51.64	22	0.000	1 - 3	0.90	1	0.343
4	Sex	52.50	22	0.000	1 - 4	0.40	1	0.527
5	Population + Age	10.48	17	0.882	2 - 5	5.75	1	0.016
6	Population + Sex	16.22	17	0.508	2 - 6	0.01	1	0.920

Cervical rib

					Calculation of			
Model					difference	Delta	Delta	
No.	Model terms	G ²	DF	Probability	statistic	G ²	DF	Probability
1	Null (no effects)	35.50	23	0.046	-	-	-	-
2	Population	25.79	18	0.105	1 - 2	9.71	5	0.084
3	Age	30.95	22	0.097	1 - 3	4.55	1	0.033
4	Sex	27.03	22	0.210	1 - 4	3.47	1	0.062
5	Age + Sex	21.90	21	0.405	3 - 5	9.05	1	0.003
6	Age + Population	23.63	17	0.130	3 - 6	7.32	5	0.198
7	Age + Sex + Population	15.59	16	0.482	5 - 7	6.31	5	0.277

L1 anticlinal unit

Model No.	Model terms	Calculation of difference						
		G ²	DF	Probability	Delta statistic	Delta G ²	Delta DF	Delta Probability
1	Null (no effects)	266.00	19	0.000	-	-	-	-
2	Population	38.71	15	0.001	1 - 2	227.30	4	0.000
3	Age	251.00	18	0.000	1 - 3	15.00	1	0.000
4	Sex	263.20	18	0.000	1 - 4	2.80	1	0.094
5	Population + Age	33.43	14	0.002	2 - 5	5.28	1	0.022
6	Population + Sex	37.35	14	0.001	2 - 6	1.36	1	0.244
7	Population + Age + Pop*Age	9.91	10	0.448	5 - 7	23.52	4	0.000
8	Population + Age + Sex	32.38	13	0.002	5 - 8	1.05	1	0.306

Lumbar rib

Model No.	Model terms	Calculation of difference						
		G ²	DF	Probability	Delta statistic	Delta G ²	Delta DF	Delta Probability
1	Null (no effects)	29.35	23	0.169	-	-	-	-
2	Population	23.22	18	0.182	1 - 2	6.13	5	0.294
3	Age	27.77	22	0.183	1 - 3	1.59	1	0.209
4	Sex	18.17	22	0.696	1 - 4	11.18	1	0.001
5	Sex + Age	16.93	21	0.715	4 - 5	1.24	1	0.265
6	Sex + Population	13.30	17	0.716	4 - 6	4.87	5	0.432

Six unit sacrum

Model No.	Model terms	Calculation of					
		G ²	DF	Probability	Delta difference statistic	Delta DF	Delta Probability
1	Null (no effects)	66.43	23	0.000	-	-	-
2	Population	40.32	18	0.002	1 - 2	26.11	5 0.000
3	Age	52.36	22	0.000	1 - 3	14.07	1 0.000
4	Sex	62.72	22	0.000	1 - 4	3.71	1 0.054
5	Population + Age	33.00	17	0.011	2 - 5	7.32	1 0.007
6	Population + Sex	33.73	17	0.009	2 - 6	6.59	1 0.010
7	Population + Age + Sex	25.47	16	0.062	5 - 7	7.53	1 0.006
8	Population + Age + Sex + Pop*Age	15.63	11	0.155	7 - 8	9.84	5 0.080
9	Population + Age + Sex + Pop*Sex	17.84	11	0.085	7 - 9	7.63	5 0.118

S₁ lumbarization

Model		Calculation of						
No.	Model terms	G ²	DF	Probability	difference statistic	Delta G ²	Delta DF	Delta Probability
1	Null (no effects)	49.22	15	0.000	-	-	-	-
2	Population	23.66	12	0.023	1 - 2	25.56	3	0.000
3	Age	47.22	14	0.000	1 - 3	2.00	1	0.157
4	Sex	43.16	14	0.000	1 - 4	6.06	1	0.014
5	Population + Sex	17.72	11	0.088	2 - 5	5.94	1	0.015
6	Population + Age	23.22	11	0.016	2 - 6	0.44	1	0.507
7	Population + Sex + Age	17.38	10	0.066	5 - 7	0.34	1	0.560
8	Population + Sex + Pop*Sex	7.14	8	0.522	5 - 8	10.58	3	0.014

S₁ cleft neural arch

Model		Calculation of						
No.	Model terms	G ²	DF	Probability	difference statistic	Delta G ²	Delta DF	Probability
1	Null (no effects)	47.19	23	0.002	-	-	-	-
2	Population	33.53	18	0.014	1 - 2	13.66	5	0.018
3	Age	45.11	22	0.003	1 - 3	2.08	1	0.149
4	Sex	33.70	22	0.053	1 - 4	13.49	1	0.000
5	Sex + Population	20.46	17	0.251	4 - 5	13.24	5	0.021
6	Sex + Age	32.28	21	0.055	4 - 6	1.42	1	0.233
7	Sex + Population + Sex*Pop	14.8	12	0.253	5 - 7	5.67	5	0.340

High sacral hiatus

Model No.	Model terms	Calculation of difference statistic					
		G ²	DF	Probability	Delta G ²	Delta DF	Delta Probability
1	Null (no effects)	33.73	23	0.069	-	-	-
2	Population	11.56	18	0.869	1 - 2	22.17	5
3	Age	32.01	22	0.077	1 - 3	1.72	1
4	Sex	33.66	22	0.053	1 - 4	0.07	1
5	Population + Age	10.74	17	0.870	2 - 5	0.82	1
6	Population + Sex	11.35	17	0.838	2 - 6	0.21	1

Appendix B. Percentage frequency and total number of observations per trait, by population group, age and sex.

Trait	Population	Male						Female						Total					
		Young		Old		Total		Young		Old		Total		Young		Old		Total	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Sternal aperture	Arctic/Inupiaq Eskimo	10	0.0	34	2.9	44	2.3	9	11.1	29	0.0	38	2.6	19	5.3	63	1.6	82	2.4
	Saint Lawrence Island	4	0.0	7	0.0	11	0.0	2	0.0	8	0.0	10	0.0	6	0.0	15	0.0	21	0.0
	South Alaskan Eskimo	13	0.0	24	0.0	37	0.0	5	0.0	23	0.0	28	0.0	18	0.0	47	0.0	65	0.0
	Ingalik (Athabaskan)	1	0.0	7	0.0	8	0.0	2	0.0	4	0.0	6	0.0	3	0.0	11	0.0	14	0.0
	Aleut	2	0.0	20	0.0	22	0.0	2	0.0	31	6.5	33	6.1	4	0.0	51	3.9	55	3.6
	Kodiak Island	14	0.0	26	3.8	40	2.5	17	5.9	23	0.0	40	2.5	31	3.2	49	2.0	80	2.5
	North Pacific Coast Indian	3	0.0	6	0.0	9	0.0	3	0.0	4	0.0	7	0.0	6	0.0	10	0.0	16	0.0
	Plains Indian	9	0.0	19	0.0	28	0.0	8	0.0	8	0.0	16	0.0	17	0.0	27	0.0	44	0.0
	Late Woodland	16	6.3	22	9.1	38	7.9	9	11.1	12	16.7	21	14.3	25	8.0	34	11.8	59	10.2
	Illinois Hopewell	9	0.0	7	0.0	16	0.0	7	0.0	13	0.0	20	0.0	16	0.0	20	0.0	36	0.0
	White	5	0.0	78	3.8	83	3.6	1	0.0	90	4.4	91	4.4	6	0.0	168	4.2	174	4.0
	Black	21	9.5	66	7.6	87	8.0	26	15.4	71	7.0	97	9.3	47	12.8	137	7.3	184	8.7
	Atlas bridge posterior	Arctic/Inupiaq Eskimo	14	0.0	51	5.9	65	4.6	11	0.0	51	3.9	62	3.2	25	0.0	102	4.9	127
Saint Lawrence Island		3	0.0	12	16.7	15	13.3	4	0.0	13	7.7	17	5.9	7	0.0	25	12.0	32	9.4
South Alaskan Eskimo		21	9.5	38	7.9	59	8.5	17	0.0	44	11.4	61	8.2	38	5.3	82	9.8	120	8.3
Ingalik (Athabaskan)		3	0.0	12	8.3	15	6.7	3	0.0	13	7.7	16	6.3	6	0.0	25	8.0	31	6.5
Aleut		12	8.3	42	14.3	54	13.0	6	16.7	48	14.6	54	14.8	18	11.1	90	14.4	108	13.9
Kodiak Island		11	9.1	18	38.9	29	27.6	10	0.0	12	0.0	22	0.0	21	4.8	30	23.3	51	15.7
North Pacific Coast Indian		5	40.0	21	9.5	26	15.4	5	0.0	10	10.0	15	6.7	10	20.0	31	9.7	41	12.2
Plains Indian		13	7.7	26	26.9	39	20.5	7	0.0	12	8.3	19	5.3	20	5.0	38	21.1	58	15.5
Late Woodland		23	26.1	26	34.6	49	30.6	13	7.7	17	5.9	30	6.7	36	19.4	43	23.3	79	21.5
Illinois Hopewell		16	31.3	14	21.4	30	26.7	6	0.0	14	7.1	20	5.0	22	0.0	28	14.3	50	18.0
White		5	0.0	92	6.5	97	6.2	2	50.0	100	3.0	102	3.9	7	14.3	192	4.7	199	5.0
Black		23	21.7	74	10.8	97	13.4	27	14.8	73	6.8	100	9.0	50	18.0	147	8.8	197	11.2

Trait	Population	Male						Female						Total					
		Young		Old		Total		Young		Old		Total		Young		Old		Total	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
<i>Atlas</i>	Arctic/Inupiaq Eskimo	13	7.7	49	6.1	62	6.5	10	10.0	49	6.1	59	6.8	23	8.7	98	6.1	121	6.6
<i>bridge</i>	Saint Lawrence Island	3	0.0	12	8.3	15	6.7	4	0.0	13	7.7	17	5.9	7	0.0	25	8.0	32	6.3
<i>lateral</i>	South Alaskan Eskimo	21	23.8	38	18.4	59	20.3	17	5.9	44	4.5	61	4.9	38	15.8	82	11.0	120	12.5
	Ingalik (Athabaskan)	3	0.0	10	10.0	13	7.7	3	0.0	13	15.4	16	12.5	6	0.0	23	13.0	29	10.3
	Aleut	12	16.7	41	9.8	53	11.3	5	20.0	48	10.4	53	11.3	17	17.6	89	10.1	106	11.3
	Kodiak Island	11	9.1	18	16.7	29	13.8	10	0.0	13	15.4	23	8.7	21	4.8	31	16.1	52	11.5
	North Pacific Coast Indian	4	0.0	19	15.8	23	13.0	5	20.0	10	30.0	15	26.7	9	11.1	29	20.7	38	18.4
	Plains Indian	13	7.7	25	12.0	38	10.5	7	0.0	12	0.0	19	0.0	20	5.0	37	8.1	57	7.0
	Late Woodland	23	4.3	26	19.2	49	12.2	13	23.1	17	17.6	30	20.0	36	11.1	43	18.6	79	15.2
	Illinois Hopewell	16	6.3	14	14.3	30	10.0	6	0.0	14	0.0	20	0.0	22	4.5	28	7.1	50	6.0
	White	5	0.0	92	0.0	97	0.0	2	0.0	99	1.0	101	1.0	7	28.6	191	0.5	198	0.5
	Black	23	4.3	74	0.0	97	1.0	27	3.7	73	1.4	100	2.0	50	0.0	147	0.7	197	1.5
<i>Atlas</i>	Arctic/Inupiaq Eskimo	11	0.0	45	4.4	56	3.6	9	0.0	42	0.0	51	0.0	20	0.0	87	2.3	107	1.9
<i>transverse</i>	Saint Lawrence Island	3	0.0	9	0.0	12	0.0	4	25.0	11	9.1	15	13.3	7	14.3	20	5.0	27	7.4
<i>foramen</i>	South Alaskan Eskimo	22	0.0	35	17.1	57	10.5	15	6.7	41	4.9	56	5.4	37	2.7	76	10.5	113	8.0
<i>defective</i>	Ingalik (Athabaskan)	3	0.0	11	9.1	14	7.1	3	0.0	11	0.0	14	0.0	6	0.0	22	4.5	28	3.6
	Aleut	12	0.0	40	2.5	52	1.9	6	0.0	47	2.1	53	1.9	18	0.0	87	2.3	105	1.9
	Kodiak Island	9	0.0	16	6.3	25	4.0	9	11.1	11	0.0	20	5.0	18	5.6	27	3.7	45	4.4
	North Pacific Coast Indian	5	0.0	13	7.7	18	5.6	5	20.0	7	14.3	12	16.7	10	10.0	20	10.0	30	10.0
	Plains Indian	13	0.0	25	0.0	38	0.0	6	0.0	12	0.0	18	0.0	19	0.0	37	0.0	56	0.0
	Late Woodland	24	0.0	30	0.0	54	0.0	13	7.7	17	0.0	30	3.3	37	2.7	47	0.0	84	1.2
	Illinois Hopewell	17	0.0	14	14.3	31	6.5	8	0.0	15	0.0	23	0.0	25	0.0	29	6.7	54	3.7
	White	5	0.0	92	5.4	97	5.2	2	0.0	94	7.4	96	7.3	7	0.0	186	6.5	193	6.2
	Black	23	21.7	73	9.6	96	12.5	27	0.0	73	8.2	100	6.0	50	10.0	146	8.9	196	9.2

Trait	Population	Male						Female						Total					
		Young		Old		Total		Young		Old		Total		Young		Old		Total	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
<i>Axis</i>	Arctic/Inupiaq Eskimo	11	0.0	50	0.0	61	0.0	7	0.0	48	0.0	55	0.0	18	0.0	98	0.0	116	0.0
<i>transverse</i>	Saint Lawrence Island	3	0.0	11	0.0	14	0.0	5	0.0	10	10.0	15	6.7	8	0.0	21	4.8	29	3.4
<i>foramen</i>	South Alaskan Eskimo	16	0.0	32	6.3	48	4.2	13	0.0	43	4.7	56	3.6	29	0.0	75	5.3	104	3.8
<i>defective</i>	Ingalik (Athabaskan)	3	0.0	13	15.4	16	12.5	3	33.3	12	0.0	15	6.7	6	16.7	25	8.0	31	9.7
	Aleut	11	9.1	38	5.3	49	6.1	6	16.7	40	2.5	46	4.3	17	11.8	78	3.8	95	5.3
	Kodiak Island	8	12.5	12	0.0	20	5.0	12	16.7	11	0.0	23	8.7	20	15.0	23	0.0	43	7.0
	North Pacific Coast Indian	5	20.0	17	0.0	22	4.5	6	33.3	7	14.3	13	23.1	11	27.3	24	4.2	35	11.4
	Plains Indian	11	0.0	23	0.0	34	0.0	8	0.0	13	0.0	21	0.0	19	0.0	36	0.0	55	0.0
	Late Woodland	22	0.0	24	0.0	46	0.0	8	0.0	15	6.7	23	4.3	30	0.0	39	2.6	69	1.4
	Illinois Hopewell	17	0.0	16	6.3	33	3.0	5	0.0	13	0.0	18	0.0	22	0.0	29	3.4	51	2.0
	White	5	0.0	92	2.2	97	2.1	2	0.0	99	0.0	101	0.0	7	0.0	191	1.0	198	1.0
	Black	23	8.7	72	2.8	95	4.2	27	3.7	74	1.4	101	2.0	50	6.0	146	2.1	196	3.1
<i>C_s double</i>	Arctic/Inupiaq Eskimo	11	45.5	46	34.8	57	36.8	6	33.3	39	25.6	45	26.7	17	4.2	85	30.6	102	32.4
<i>transverse</i>	Saint Lawrence Island	2	0.0	9	22.2	11	18.2	3	0.0	10	30.0	13	23.1	5	0.0	19	26.1	24	20.8
<i>foramen</i>	South Alaskan Eskimo	20	65.0	34	61.8	54	63.0	15	53.3	32	34.4	47	40.4	35	60.0	66	48.5	101	52.5
	Ingalik (Athabaskan)	2	50.0	10	60.0	12	58.3	3	66.7	11	63.6	14	64.3	5	60.0	21	61.9	26	61.5
	Aleut	7	42.9	36	44.4	43	44.2	5	60.0	32	31.3	37	35.1	12	50.0	68	38.2	80	40.0
	Kodiak Island	7	71.4	21	28.6	28	39.3	13	53.8	18	16.7	31	32.3	20	60.0	39	23.1	59	35.6
	North Pacific Coast Indian	8	75.0	17	35.3	25	48.0	3	0.0	6	16.7	9	11.1	11	54.5	23	30.4	34	38.2
	Plains Indian	13	38.5	22	72.7	35	60.0	8	50.0	10	40.0	18	44.4	21	42.9	32	62.5	53	54.7
	Late Woodland	26	53.8	21	57.1	47	55.3	13	61.5	12	50.0	25	56	39	56.4	33	54.5	72	55.6
	Illinois Hopewell	15	26.7	15	33.3	30	30.0	5	80.0	12	33.3	17	47.1	20	40.0	27	33.3	47	36.2
	White	5	40.0	92	39.1	97	39.2	2	0.0	95	40.0	97	39.2	7	28.6	187	39.6	194	39.2
	Black	23	34.8	72	33.3	95	33.7	27	40.7	72	30.6	99	33.3	50	38.0	144	31.9	194	33.5

Trait	Population	Male						Female						Total					
		Young		Old		Total		Young		Old		Total		Young		Old		Total	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
<i>C₇ costal transverse foramen</i>	Arctic/Inupiaq Eskimo	9	0.0	35	14.3	44	11.4	5	40.0	35	25.7	40	27.5	14	14.3	70	20.0	84	19.0
	Saint Lawrence Island	3	0.0	8	12.5	11	9.1	3	0.0	8	37.5	11	27.3	6	0.0	16	25.0	22	18.2
	South Alaskan Eskimo	21	19.0	28	17.9	49	18.4	12	8.3	26	26.9	38	21.1	33	15.2	54	22.2	87	19.5
	Ingalik (Athabaskan)	2	0.0	11	9.1	13	7.7	2	0.0	12	0.0	14	0.0	4	0.0	23	4.3	27	3.7
	Aleut	5	0.0	32	9.4	37	8.1	3	0.0	35	5.7	38	5.3	8	0.0	67	7.5	75	6.7
	Kodiak Island	6	0.0	12	0.0	18	0.0	12	0.0	12	8.3	24	4.2	18	0.0	24	4.2	42	2.4
	North Pacific Coast Indian	5	20.0	10	10.0	15	13.3	5	40.0	4	0.0	9	22.2	10	30.0	14	7.1	24	16.7
	Plains Indian	10	0.0	23	8.7	33	6.1	9	22.2	10	10.0	19	15.8	19	10.5	33	9.1	52	9.6
	Late Woodland	18	11.1	17	41.2	35	25.7	12	8.3	14	21.4	26	15.4	30	10.0	31	32.2	61	21.3
	Illinois Hopewell	14	14.3	9	0.0	23	8.7	6	16.7	10	20.0	16	18.8	20	15.0	19	10.5	39	12.8
	White	5	0.0	92	5.4	97	5.2	2	0.0	95	4.2	97	4.1	7	0.0	187	4.8	194	4.6
	Black	23	4.3	70	7.1	93	6.5	25	4.0	71	2.8	96	3.1	48	4.2	141	5.0	189	4.8
	<i>Cervical rib</i>	Arctic/Inupiaq Eskimo	9	0.0	33	0.0	42	0.0	4	0.0	25	4.0	29	3.4	13	0.0	58	1.7	71
Saint Lawrence Island		3	0.0	7	0.0	10	0.0	2	0.0	5	0.0	7	0.0	5	0.0	12	0.0	17	0.0
South Alaskan Eskimo		22	0.0	26	0.0	48	0.0	10	0.0	18	0.0	28	0.0	32	0.0	44	0.0	76	0.0
Ingalik (Athabaskan)		2	0.0	11	9.1	13	7.7	2	0.0	11	0.0	13	0.0	4	0.0	22	4.5	26	3.8
Aleut		5	0.0	20	0.0	25	0.0	3	0.0	29	3.4	32	3.1	8	0.0	49	2.0	57	1.8
Kodiak Island		5	0.0	14	0.0	19	0.0	15	13.3	15	0.0	30	6.7	20	10.0	29	0.0	49	4.1
North Pacific Coast Indian		3	0.0	4	0.0	7	0.0	4	0.0	3	0.0	7	0.0	7	0.0	7	0.0	14	0.0
Plains Indian		12	8.3	22	0.0	34	2.9	9	0.0	9	22.2	18	11.1	21	4.8	31	6.5	52	5.8
Late Woodland		16	12.5	15	0.0	31	6.5	13	15.4	11	0.0	24	8.3	29	13.8	26	0.0	55	7.3
Illinois Hopewell		13	0.0	5	0.0	18	0.0	5	0.0	8	0.0	13	0.0	18	0.0	13	0.0	31	0.0
White		5	0.0	88	0.0	93	0.0	2	0.0	89	2.2	91	2.2	7	0.0	177	1.1	184	1.1
Black		23	0.0	67	0.0	90	0.0	25	0.0	71	4.2	96	3.1	48	0.0	138	2.2	186	1.6

Trait	Population	Male						Female						Total					
		Young		Old		Total		Young		Old		Total		Young		Old		Total	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
<i>L₁ anticlinal unit</i>	Arctic/Inupiaq Eskimo	17	47.1	51	31.4	68	35.3	9	44.4	51	29.4	60	31.7	26	46.2	102	30.4	128	33.6
	Saint Lawrence Island	3	100.0	17	35.3	20	45.0	4	100.0	16	6.3	20	25.0	7	100.0	33	21.2	40	35.0
	South Alaskan Eskimo	27	85.2	45	60.0	72	69.4	22	77.3	53	49.1	75	57.3	49	81.6	98	54.1	147	63.3
	Ingalik (Athabaskan)	2	50.0	13	30.8	15	33.3	3	33.3	14	21.4	17	23.5	5	40.0	27	25.9	32	28.1
	Aleut	6	50.0	42	31.0	48	33.3	3	33.3	43	32.6	46	32.6	9	44.4	85	31.8	94	33.0
	Kodiak Island	17	64.7	33	84.8	50	78.0	22	72.7	27	92.6	49	83.7	39	69.2	60	88.3	99	80.8
	North Pacific Coast Indian	7	14.3	21	23.8	28	21.4	7	28.6	8	25.0	15	26.7	14	21.4	29	24.1	43	23.3
	Plains Indian	14	71.4	21	52.4	35	60.0	9	33.3	11	36.4	20	35.0	23	56.5	32	46.9	55	50.9
	Late Woodland	32	68.8	28	71.4	60	70.0	13	76.9	21	57.1	34	64.7	45	71.1	49	65.3	94	68.1
	Illinois Hopewell	10	50.0	12	66.7	22	59.1	8	62.5	14	57.1	22	59.1	18	55.6	26	61.5	44	59.1
	White	5	0.0	92	0.0	97	0.0	2	0.0	99	3.0	101	3.0	7	0.0	191	1.6	198	1.5
	Black	23	0.0	73	6.8	96	5.2	27	3.7	73	11.0	100	9.0	50	2.0	146	8.9	196	7.1
	<i>Lumber rib</i>	Arctic/Inupiaq Eskimo	15	46.7	38	23.7	53	30.2	6	33.3	31	16.1	37	18.9	21	42.9	69	20.3	90
Saint Lawrence Island		4	0.0	9	11.1	13	7.7	4	25.0	11	0.0	15	6.7	8	12.5	20	5.0	28	7.1
South Alaskan Eskimo		23	0.0	29	17.2	52	9.6	21	9.5	33	9.1	54	9.3	44	4.5	62	12.9	106	9.4
Ingalik (Athabaskan)		2	0.0	10	30.0	12	25.0	2	0.0	8	12.5	10	10.0	4	0.0	18	22.2	22	18.2
Aleut		6	50.0	33	9.1	39	15.4	4	0.0	36	11.1	40	10.0	10	30.0	69	10.1	79	12.7
Kodiak Island		16	12.5	33	21.2	49	18.4	20	10.0	24	8.3	44	9.1	36	11.1	57	15.8	93	14.0
North Pacific Coast Indian		4	0.0	4	0.0	8	0.0	1	0.0	1	0.0	2	0.0	5	0.0	5	0.0	10	0.0
Plains Indian		13	7.7	17	11.8	30	10.0	9	11.1	10	0.0	19	5.3	22	9.1	27	7.4	49	8.2
Late Woodland		30	20.0	29	17.2	59	18.6	10	10.0	15	26.7	25	20.0	40	17.5	44	20.5	84	19.0
Illinois Hopewell		11	18.2	9	22.2	20	20.0	4	0.0	10	0.0	14	0.0	15	13.3	19	10.5	34	11.8
White		5	20.0	92	13.0	97	13.4	2	0.0	95	4.2	97	4.1	7	14.3	187	8.6	194	8.8
Black		22	13.6	72	19.4	94	18.1	26	7.7	73	6.8	99	7.1	48	10.4	145	13.1	193	12.4

Trait	Population	Male						Female						Total						
		Young		Old		Total		Young		Old		Total		Young		Old		Total		
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	
<i>Six unit sacrum</i>	Arctic/Inupiaq Eskimo	14	35.7	44	45.5	58	43.1	9	44.4	36	38.9	45	40.0	23	39.1	80	42.5	103	41.7	
	Saint Lawrence Island	4	0.0	23	34.8	27	29.6	5	60.0	33	30.3	38	34.2	9	33.3	56	32.1	65	32.3	
	South Alaskan Eskimo	30	23.3	41	39.0	71	32.4	20	35.0	45	35.6	65	35.4	50	28.0	86	37.2	136	33.8	
	Ingalik (Athabaskan)	3	66.7	11	18.2	14	28.6	4	0.0	4	0.0	8	0.0	7	28.6	15	13.3	22	18.2	
	Aleut	9	55.6	50	42.0	59	44.1	3	33.3	58	20.7	61	21.3	12	50.0	108	30.6	120	32.5	
	Kodiak Island	21	23.8	26	53.8	47	40.4	19	10.5	26	34.6	45	24.4	40	14.0	52	44.2	92	32.6	
	North Pacific Coast Indian	3	0.0	11	27.3	14	21.4	0	0.0	6	33.3	6	33.3	3	0.0	17	29.4	20	25.0	
	Plains Indian	13	7.7	33	24.2	46	19.6	9	22.2	21	19.0	30	20.0	22	13.6	54	22.2	76	19.7	
	Late Woodland	36	11.1	28	39.3	64	23.4	10	0.0	15	13.3	25	8.0	46	8.7	43	30.2	89	19.1	
	Illinois Hopewell	10	20.0	8	75.0	18	44.4	8	0.0	12	25.0	20	15.0	18	11.1	20	45.0	38	28.9	
	White	5	20.0	84	52.4	89	50.6	2	50.0	99	41.4	101	41.6	7	28.6	183	46.4	190	45.8	
	Black	23	47.8	74	43.2	97	44.3	27	29.6	74	47.3	101	42.6	50	38.0	148	45.3	198	43.4	
	<i>S, cleft neural arch</i>	Arctic/Inupiaq Eskimo	15	26.7	57	12.3	72	15.3	11	0.0	47	2.1	58	1.7	26	15.4	104	7.7	130	9.2
		Saint Lawrence Island	4	0.0	32	9.4	36	8.3	5	20.0	37	8.1	42	9.5	9	11.1	69	8.7	78	9.0
South Alaskan Eskimo		31	16.1	56	12.5	87	13.8	26	19.2	56	17.9	82	18.3	57	17.5	112	15.2	169	16.0	
Ingalik (Athabaskan)		5	0.0	15	20.0	20	15.0	5	0.0	16	6.3	21	4.8	10	0.0	31	12.9	41	9.8	
Aleut		7	0.0	59	5.1	66	4.5	3	0.0	68	2.9	71	2.8	10	0.0	127	43.3	137	3.6	
Kodiak Island		21	9.5	24	16.7	45	13.3	18	11.1	26	0.0	44	4.5	39	10.3	50	8.0	89	9.0	
North Pacific Coast Indian		4	0.0	15	0.0	19	0.0	3	33.3	8	0.0	11	9.1	7	14.3	23	0.0	30	3.3	
Plains Indian		14	21.4	35	2.9	49	8.2	11	36.4	24	16.7	35	22.9	25	28.0	59	8.5	84	14.3	
Late Woodland		41	17.1	33	12.1	74	14.9	13	7.7	21	9.5	34	8.8	54	14.8	54	11.1	108	13.0	
Illinois Hopewell		14	0.0	11	0.0	25	0.0	7	28.6	14	14.3	21	19	21	9.5	25	8.0	46	8.7	
White		5	0.0	92	21.7	97	20.6	2	0.0	100	8.0	102	7.8	7	0.0	192	14.6	199	14.1	
Black		23	17.4	74	13.5	97	14.4	27	11.1	74	1.4	101	4	50	14.0	148	7.4	198	9.1	

Trait	Population	Male						Female						Total					
		Young		Old		Total		Young		Old		Total		Young		Old		Total	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
<i>High sacral hiatus</i>	Arctic/Inupiaq Eskimo	15	0.0	50	8.0	65	6.2	10	40.0	43	9.3	53	15.1	25	16.0	93	8.6	118	10.2
	Saint Lawrence Island	4	25.0	23	8.7	27	11.1	5	0.0	32	0.0	37	0.0	9	11.1	55	3.6	64	4.7
	South Alaskan Eskimo	26	7.7	47	8.5	73	8.2	22	4.5	54	9.3	76	7.9	48	6.3	101	8.9	149	8.1
	Ingalik (Athabaskan)	3	33.3	15	0.0	18	5.6	5	0.0	12	8.3	17	5.9	8	12.5	27	3.7	35	5.7
	Aleut	9	0.0	59	1.7	68	1.5	3	0.0	62	3.2	65	3.1	12	0.0	121	2.5	133	2.3
	Kodiak Island	21	14.3	25	4.0	46	8.7	18	5.6	25	4.0	43	4.7	39	10.3	50	4.0	89	6.7
	North Pacific Coast Indian	2	50.0	13	7.7	15	13.3	1	0.0	6	0.0	7	0.0	3	33.3	19	5.3	22	9.1
	Plains Indian	12	8.3	33	9.1	45	8.9	11	0.0	23	13.0	34	8.8	23	4.3	56	10.7	79	8.9
	Late Woodland	38	0.0	29	3.4	67	1.5	13	0.0	16	0.0	29	0.0	51	0.0	45	2.2	96	1.0
	Illinois Hopewell	9	11.1	9	11.1	18	11.1	7	0.0	11	0.0	18	0.0	16	6.3	20	5.0	36	5.6
	White	5	0.0	91	2.2	96	2.1	2	0.0	98	2.0	100	2.0	7	0.0	189	2.1	196	2.0
	Black	23	4.3	73	2.7	96	3.1	27	3.7	74	0.0	101	1.0	50	4.0	147	1.4	197	2.0