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Fluctuating Dental Asymmetry and Stress at the Averbuch Site (40DV60), Nashville, Tennessee

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To the Graduate Council:

I am submitting herewith a thesis written by Mark F. Guagliardo entitled "Fluctuating Dental Asymmetry and Stress at the Averbuch Site (40DV60), Nashville, Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

Fred H. Smith, Major Professor

We have read this thesis and recommend its acceptance:

William M. Bass, R. L. Jantz, Walter E. Klippel

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

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and recommend its acceptance:

William M. Bass

Walter E. Klippel

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

A

FLUCTUATING DENTAL ASYMMETRY AND STRESS AT THE AVERBUCH SITE (40DV60), NASHVILLE, TENNESSEE

A Thesis
Presented for the
Master of Arts
Degree
The University of Tennessee, Knoxville

Mark F. Guagliardo
March 1980

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ABSTRACT

There may exist bilateral asymmetry in tooth size in which neither side tends to be larger within a population. Such a bilaterally random distribution of asymmetry is called fluctuating dental asymmetry. One of its major causes is the exposure of individuals to stress during the time of tooth formation. Stressors known to increase fluctuating dental asymmetry are protein deficiency, heat, cold, and noise; there are probably many others as yet undiscovered.

This study explores the patterns of fluctuating dental asymmetry at the Averbuch site, a Mississippian village and three cemeteries near Nashville, Tennessee. The effects of tooth size, dentition type, sex, and cemetery affiliation on dental asymmetry are examined. Regression analysis shows that there is a scaling effect of tooth size on asymmetry, necessitating that tooth size be corrected for before the other factors are examined. Analysis of correlation coefficients reveals that four pairs of deciduous teeth are significantly less symmetrical and two pairs are significantly more symmetrical than the permanent antimeres. Analysis of correlation coefficients and ANOVA reveal that females are somewhat more symmetrical than males, suggesting that they are developmentally more stable than males.

Although it is difficult to interpret the meaning of the deciduous-permanent differences, both types of dentition show the same intercemetery patterns of dental asymmetry. Cemetery 2 (undatable) is the most asymmetrical, Cemetery 3 is the least asymmetrical, and Cemetery 1 is intermediate in its rank of asymmetry. Archeological

evidence suggests that Cemetery 1 is younger than Cemetery 3. These findings support the hypothesis of increasing population pressure in the Nashville Basin at the time of the site's occupation. However, the true temporal relationship of the cemeteries is not known for certain. Further statements await the analysis of archeological materials recovered from the site.

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CHAPTER I

INTRODUCTION

The Averbuch site is a late Mississippian site located in the Bordeaux area of northern Davidson County, Tennessee. This area is a transitional zone between the Nashville Basin and the Highland Rim of middle Tennessee. Excavation was begun in 1975 by the Tennessee Division of Archaeology, because the site was threatened by expansion of a Nashville subdivision. The University of Tennessee, Knoxville Department of Anthropology contracted with the Heritage Conservation and Recreation Service for a long-term excavation in 1977 and 1978 under the direction of Drs. William M. Bass and Walter H. Klippel.

The site consisted of a stockaded village and three cemeteries. Cemetery 1 contained 556 skeletons, Cemetery 2 contained 96 skeletons, and Cemetery 3, which was partially destroyed by a road, contained 191 individuals. Thirty-six individuals were associated with other features of the site, giving a total of 879 individuals from the site.

It is unfortunate that there are no C-14 dates for the cemeteries. However, tentative archeological evidence suggests that Cemetery 3 predates Cemetery 1. The village stockade intersects Cemetery 3, indicating that it was probably abandoned by the time the villagers felt it was necessary to build the stockade. While in the field, the excavators also noticed that temporally diagnostic artifacts tended to be associated with the two cemeteries in a way that suggested Cemetery 1 is later. Cemetery 2 can not be dated.

Because of the large number of skeletons from the site, the excavators decided that a biocultural approach to excavation and analysis of the site's resources would be most fruitful in providing information about the nature of the people who occupied the site. As the name implies, biocultural anthropology examines both the biological and cultural aspects of extant or archeological populations in hopes that each realm will help to explain the other and that a better general understanding of the population investigated will be achieved. This intradisciplinary approach was suggested as early as 1942 by Chapple and Coon, and was supported by Washburn (1952), who criticized the study of anthropometrics, skeletal typologies, and the like, as ends unto themselves. As Blakely (1977) points out, skeletal biologists and archeologists have more recently heeded the call to use an integrated approach: Blakely (1976) on the genetic relationship of skeletal populations; Owsley et al. (in press) in helping to define archeological phases; Perzigian (1975) on microevolutionary change; Angel (1969) on disease vectors; and Hatch and Willey (1974), and Peebles (1974) on socioeconomic status to name a few.

The biocultural approach depends on the existence of detectable relationships between the biological and cultural variables of the population being studied. This thesis investigates the relationship between a biological measure of developmental stress, fluctuating dental asymmetry, and the cultural variable of the cemetery in which the individual is buried. It is hoped that the patterns revealed will be an aid in understanding the social organization and health status of the Averbuch people.

The Middle Cumberland Culture

Averbuch belongs to the Middle Cumberland culture of the Mississippian Period. This culture is commonly referred to as the "Stone Box" culture because of its propensity toward burying the dead in limestone, sandstone, or slate boxes (Ferguson, 1972). The greatest intensity of the culture is in the Cumberland River Valley in the vicinity of Nashville, Tennessee. Carbon-14 dates and diagnostic artifacts place the culture between 1200 A.D. and 1700 A.D. (Ferguson, 1972). The large number of stone box graves found in the region indicates that the area was densely populated at one time. G. P. Thurston (1897) found more than 3000 graves at the Noel Farm site (now in Nashville), and 3000 to 4000 on Brown's Creek near Nashville. The following excerpt from Thurston (1897:28) also attests to the high population density reached by the Middle Cumberland people:

> Professor Putnam and his assistants explored about six thousand graves, the majority of them in the vicinity of Nashville. Dr. Jones examined a large number in some 15 different cemeteries. Dr. Troust, the learned geologist of Tennessee, reportes (sic) 6 very large cemeteries near Nashville.

For unknown reasons the people of the Middle Cumberland Culture abruptly disappeared sometime before 1700 A.D. In the middle seventeenth century the Shawnee migrated from Florida and Georgia to the Nashville area but were banished from the region by the Cherokee and Chickasaw early in the eighteenth century. No one has ever suggested that the brief occupation of the Cumberland Valley by the Shawnee caused the downfall of the Stone Box people. It may be that epidemic diseases introduced by European explorers took devasting tolls on the society. The following passage from Ferguson (1972:45) suggests this as well as other possibilities:

> Such factors as introduced epidemic diseases, pressure from the armed Iroquois (who raided as far south as northern Alabama and claimed the land at the time of the Treaty of Fort Stanwix), encroachment by displaced Algonquin tribes, and French and Spanish manipulations in the south, could have served to radiate shock waves that led to displacement or elimination.

Population pressure on available resources may also have reached an intolerable level. Fluctuating dental asymmetry might be sensitive to any of these causes.

Purposes

Three goals are pursued in this investigation. The first is to search for cemetery differences in fluctuating dental asymmetry at Averbuch. The intercemetery patterns of asymmetry will be used to generate testable hypotheses to explain the differences. Hopefully, suggestions can then be made regarding the nature of the Averbuch social organization.

The second goal of this study is to investigate the strictly biological question of differences between males and females in dental asymmetry. As will be explained in Chapter 2, dental asymmetry is influenced by fetal and early childhood developmental stability. Because females seem to be better able to resist stressful forces that disturb biological development than males (Garn et al., 1966, 1967; Jantz, 1978), I will test the hypothesis that fluctuating dental asymmetry is lower among females than males.

The third and final goal of this thesis is to examine the patterns of fluctuating asymmetry within the deciduous dentition of

Averbuch. To my knowledge, only one report appears in the literature that briefly addresses fluctuating asymmetry of the deciduous teeth (Moorrees and Reed, 1964). Using deciduous teeth will significantly extend the period of biological development over which fluctuating dental asymmetry can be used to measure developmental stability. I will compare deciduous with permanent fluctuating asymmetry, and will examine the cemetery patterning of asymmetry of the deciduous dentition for the same reasons as for permanent teeth.

CHAPTER II

THE MEANING OF FLUCTUATING DENTAL ASYMMETRY

The genetic makeup of an organism dictates that organs should grow along certain developmental pathways. Waddington (1962) called these developmental tendencies "canalization." Deviation from a canalized path of development may be caused by "noise" or disturbances inflicted upon the developing organism as a whole or specifically on an organ in question (Waddington, 1957; Mather, 1953). This stress may take the form of heat, cold, sound, and nutritional deficiency, among other things (Siegel et al., 1977; Siegel and Doyle, 1975a & b; Siegel and Smookler, 1973; and Sciulli et al., 1979). For bilateral organs such as teeth, it can be assumed that genes controlling development, and thus the strength of canalization, have identical influence on the organs of each side (Adams and Niswander, 1967).

Because localized stress may randomly affect the organ of one side of the body more than another, the side more affected will deviate more from the canalized pathway. The result is bilateral asymmetry in size, shape, or structure. Asymmetries caused by these disturbances are distributed randomly from side to side within a breeding population. Van Valen (1962) termed such a distribution "fluctuating asymmetry." Mather (1953), working with bilateral asymmetry of sternopleural chaetae number in Drosphila melanogaster, was the first to recognize that fluctuating asymmetry could be used as a measure of developmental homeostasis. It follows that under proper conditions fluctuating asymmetry can be used to measure the amount of noise or stress that individuals making up various populations experience during growth.

Other influences besides stress may affect the patterns of bilateral asymmetry within and between individuals and populations. These include individual inbreeding coefficient (F), amount of inbreeding in a population, severe congenital abnormalities, gender, and size of the organ studied.

The increased homozygosity that results from inbreeding allows a higher probability of the expression of deleterious alleles in the phenotype (Bodmer and Cavalli-Sforza, 1976:373-375). This "weakening" of the organism makes it more susceptible to forces that would cause it to deviate from proper pathways of development. Homozygosity also decreases the number of alternative pathways of development, which are needed when stress induces a block in a pathway (Waddington, 1957:49). Therefore, one might expect that higher F's would be accompanied by higher levels of asymmetry. I am not certain that the inbreeding coefficient is a significant factor in asymmetry studies of normally breeding populations. Niswander and Chung (1965) found a relationship between F and asymmetry of the permanent lower central incisors of Japanese children. However, only marriages of first cousins once removed resulted in significantly increased fluctuating dental asymmetry. Bailit et al. (1970) found no relationship between F and asymmetry in the relatively inbred Tristanite Islanders.

On the other hand, Bailit et al. (1970) also compared the level of fluctuating asymmetry of four populations ranked according to amount of inbreeding. Their asymmetry ranking was the same as for degree of inbreeding. Working with rats, Bader (1965) showed that inbreeding was associated with higher asymmetry levels. He found that inbred and hybrid strains were more asymmetrical than wild and randomly bred strains.

I will work under the tentative assumption that homozygosity was not an important factor in the Averbuch population, because it is difficult to imagine inbreeding reaching the levels in the rat studies cited. In addition, there is ethnographic evidence that suggest some Indians of the southeastern United States practiced moiety exogamy (Hudson, 1976:237).

Genetic diseases may be accompanied by detectably increased amounts of asymmetry. Adams and Niswander (1967) showed this to be the case for the teeth and palm prints of cleft-lip and cleft-palate patients as compared with controls. Though his results were not as clear, Owsley (1978) found similar tendencies among cleft-lip and cleft-palate patients for finger and palm prints.

Many researchers have found for the dentition (Garn et al., 1965, 1966, 1967) and dermatoglyphics (Jantz, 1978; Owsley, 1978; and Webb, 1977) that females are less asymmetrical than males. All believe their results indicate that females are developmentally more homeostatic than males, but their suggested reasons for this differ. Garn and associates believe that the extra X chromosome of females provides extra developmental control and more protection from developmental accidents to its bearer. Mittwoch (1973:183-184) and Jantz (1978) suggest that the heterochromatic nature of the redundant X chromosome slows down the rate of mitotic division, the result being more control over developmental events.

Whatever the reasons for higher developmental stability in females, it should be accompanied by less asymmetry. This has been demonstrated by Garn et al. (1967) and Moorrees and Reed (1964) for teeth, Jantz (1978, 1980) for dermatoglyphics, and Webb (1977) for teeth and dermatoglyphics.

Soule (1976) found a significant correlation ($P < 0.01$) between mean auricular scale length and auricular scale length asymmetry in 20 populations of the side-blotched lizard (Uta stansburiana). He suggests that, where laterality of absolute organ size is concerned, it is reasonable to predict a scaling effect of size on asymmetry. In other words, as mean organ size increases, asymmetry increases. To illustrate, a pair of elephants and a pair of mice may differ in weight by ten percent for each pair. But in absolute pound differences the mice appear to be much more similar to each other.

The same reasoning may apply to antimeric pairs of teeth. Van Valen (1962) "observed" this scaling effect in the dentition of fossil horses and corrected for it, though he did not say how it was observed or how significant it was. Garn et al. (1966) also found a strong relationship between tooth size and asymmetry in the dentition of modern Ohio whites; larger teeth were more asymmetrical. Surprisingly, DiBennardo (1973:115) found that among Japanese children smaller teeth were more asymmetrical than larger teeth. He believes this is so because asymmetry and smaller tooth size may result from the same stresses. These conflicting findings suggest that the relationship of fluctuating dental asymmetry and tooth size should be explored within the Averbuch population.

Under the category of "stresses" I have placed the remaining factors that have been demonstrated or suggested to influence fluctuating asymmetry. In rats, heat (Siegel et al., 1977), cold (Siegel and Doyle, 1975a), audiogenic stress (Siegel and Doyle, 1975b; Siegel and Smookler, 1973), and protein deficiency (Sciulli et al., 1979) significantly increase fluctuating dental asymmetry. All of these investigations were conducted with proper methodology under strict laboratory conditions and demonstrate that the influences of these stresses can affect asymmetry independently of the genetic factors mentioned above.

Of particular interest is the work by Sciulli et al. (1979) on the interactions of heat, cold, noise, and protein deprivation on the dental asymmetry of rats. This is the only study to attempt to quantify a nutritional deficiency before measuring its effect on asymmetry. The results showed that protein deprivation had a greater effect than the other three sources of stress. A problem with an experiment of this nature is to determine what are meaningfully equivalent amounts of each kind of stress that should be used on the various groups of rats. Still, the important fact here, is that protein deprivation, which may have accompanied the purported population pressures of the Nashville basin circa the seventeenth century A.D., can increase dental asymmetry.

Among living and skeletal human populations, there is some evidence that socioeconomic status, nutritional well-being, and the degree to which technological development buffers environmental effects can influence dental development. Bailit et al. (1970) ranked their four living populations in order of increasing technological sophistication and found that their fluctuating dental asymmetry rank increased in the opposite direction. Doyle and Johnston (1977) found that Eskimo and Pueblo Indian skeletons possess significantly more fluctuating dental asymmetry than modern Ohio whites. In another interpopulation comparison, Perzigian (1977) found that individuals from a prehistoric hunting and gathering site (Indian Knoll (24OH2)) were dentally more asymmetrical than aboriginal farmers (Campbel (23PM5) and Larson (39WW2) sites). Both of these groups were more asymmetrical than Caucasions of the Hamann-Todd cadaver collection.

I have no quarrel with the prediction that groups with low socioeconomic status, low technological development, or nutritional problems will have more dental asymmetry than would be the case otherwise. However, I think it can be misleading to make any comparison in a stress indicator between populations sampled from different times and places as is the case with each of the three studies cited above. It is difficult and sometimes impossible to determine what kinds of stress affected each group, how intensely a group was exposed to each stress, or for how long the group had been exposed to the stress at the time of sampling. This latter point is important because natural selection can make one population more resistant to a given stress than another population if the former group has been exposed to the stress longer. It can be seen that comparisons of subgroups within a single population will minimize these factors, and conclusions drawn from asymmetry differences will be more sound than would be the case for interpopulation comparisons.

An example of an intrapopulation comparison is the report by Enwonwu (1973). He used timing of eruption and enamel hypoplasia of the deciduous teeth as prenatal measures of stress and found that underpriviledged Yoruban children from Nigeria were significantly more stressed than their counterparts from wealthier homes. Using data collected from post-World War II Japanese children, DiBennardo (1973) found significant canonical correlations between dental asymmetry on the one hand and socioeconomic status on the other. However, analyzing the same data with regression analysis, he found no such relationship (DiBennardo and Bailit, 1978).

In the following chapters, I will use a methodology that will correct for sexual differences and for any scaling effects of tooth size on asymmetry. I will assume that the frequency of serious congenital abnormalities and the level of inbreeding at Averbuch are too low to significantly influence statistical tests. If these two factors do occur, it is assumed that they are randomly distributed among cemeteries. Therefore stress, as defined above, will be the factor used to explain the results of this exploratory study.

CHAPTER III

THE MEASUREMENTS

Fluctuating dental asymmetry reflects deviation from genetically determined tooth size. It is, therefore, necessary to use measurements that reflect as nearly as possible this genetic dictum and deviation from it. The literature provides numerous dental measuring techniques from which to choose. I found it necessary to develop my own measurements because those in the literature would allow too much "noise" to mask the very small side differences in tooth size. Here the term noise refers to any source of bilateral difference in measurement other than stress, such as differential attrition between the sides or failure to account for lateral difference in the amount of tooth rotation.

To some readers, my measurements may seem unnecessarily complex and difficult to follow. In addition, the criteria for excluding teeth from the measured sample are quite strict. Therefore, some previously used dental measurements are critiqued below. The purpose of this review is to emphasize the importance of preserving the very subtle stress-induced asymmetry by the use of the measurements and techniques developed for the present study.

Schuman and Brace (1954) and Hrdlička (1952) define the mesiodistal length (hereafter referred to as MD) as the distance between points of contact with adjacent teeth measured midway between the buccal and lingual sides of the tooth. They define the buccolingual diameter (hereafter referred to as BL) as the maximum measurement perpendicular to MD. With this method, neither interstitial wear nor tooth rotation is adjusted for. Reference points are given for only two dimensions, while teeth are of course three dimensional objects. Thus, measurements can change by tilting the caliper in relation to the occlusal plane with their method.

Improving slightly upon this method, Greene et al. (1967), Perzigian (1977), Tobias (1967), and Wolpoff (1971) define MD as the maximum distance parallel to the occlusal and labial surfaces between the points of contact or where the points of contact would normally occur. They define BL as the maximum measurement perpendicular to this. Sometimes it is difficult to identify points of contact. In addition, the labial surface should not be used as a measuring reference for canines and premolars because it is usually rounded, and determining its orientation is too subjective.

Noise finds its way into these measurements when one is measuring teeth not in their sockets. This is because "points of contact" or "where points of contact would normally occur" is dependent on the tooth's orientation within the mouth. I sometimes found it difficult to determine where these points were on teeth that could not be placed into their alveoli.

The noise allowed by these measurements seems to be insignificant for the studies in which they were used. However, I found size differences between the sides to be most frequently on the order of one tenth or a few tenths of a millimeter. Measurements preserving these miniscule differences should be based on two or more landmarks that are genetically inherent in the tooth. The best measurements available are those used by DiBennardo (1973), which were developed specifically for a study of fluctuating dental asymmetry. Unfortunately, his reference points for molars are cones and conids. Thus, the vast majority of crowns from the Averbuch site would have had to been excluded from the sample because occlusal wear, always heavy among native Americans, rapidly destroys landmarks.

Every identifiable, measurable tooth from the Averbuch site was measured, but only paired teeth were used in the analyses (i.e., when both the left and right tooth of an antimeric pair were present). A Helios dial caliper was used; recordings were taken to the nearest tenth of a millimeter. All readings were taken at least twice. Both MD and BL[1] measurements were taken, but interstitial wear resulted in very few MD observations. Thus, MD measurements were not used in this study, and only BL measurements are described below and illustrated in Figures 1 and 2.

In my technique for measuring incisors and canines, the measuring arms of the caliper are held parallel to the vertical axis of the tooth in the mesiodistal and labiolingual planes. The measurement was the maximum reading found by moving the caliper in the MD dimension.

For premolars and molars, the measuring arms of the calipers were held in or near the occlusal plane and perpendicular to a line bisecting the angle formed by the mesial and distal surfaces. The arms were held perpendicular to the mesial and distal surfaces if those surfaces were parallel to each other. The maximum reading was recorded.

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[1] For anterior teeth, the term labiolingual should be substituted for buccolingual.

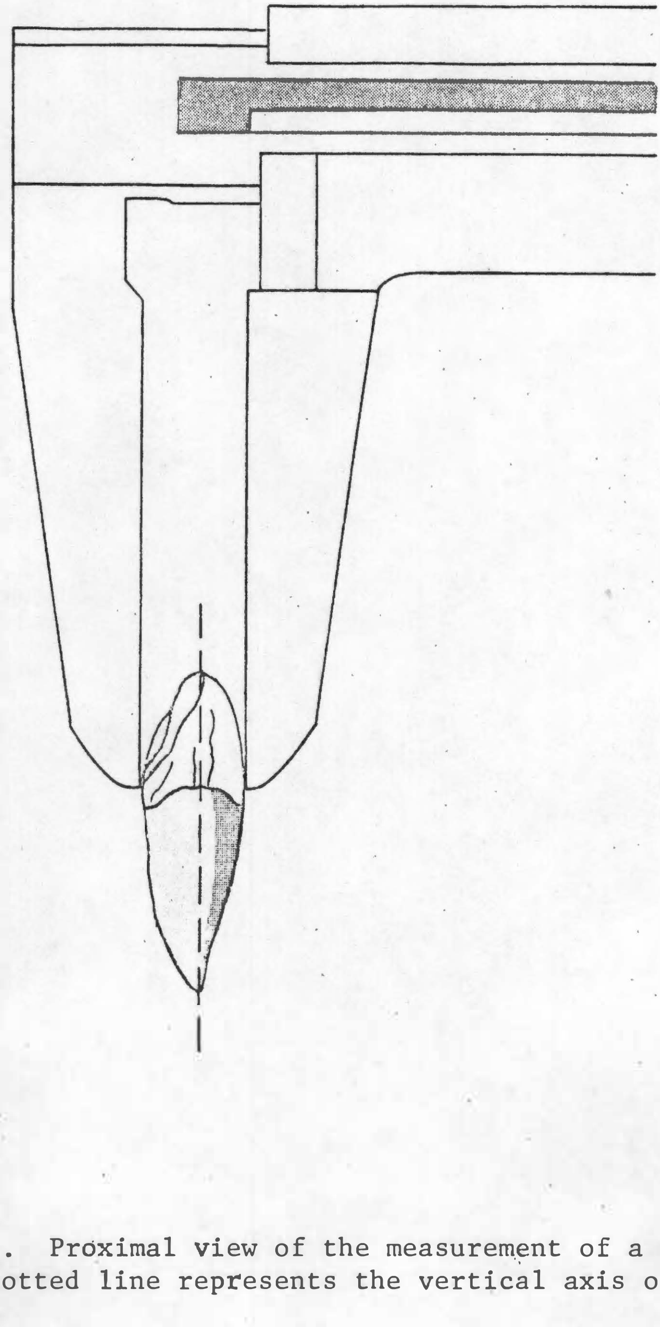

Figure 1. Proximal view of the measurement of a mandibular canine. The dotted line represents the vertical axis of the tooth.

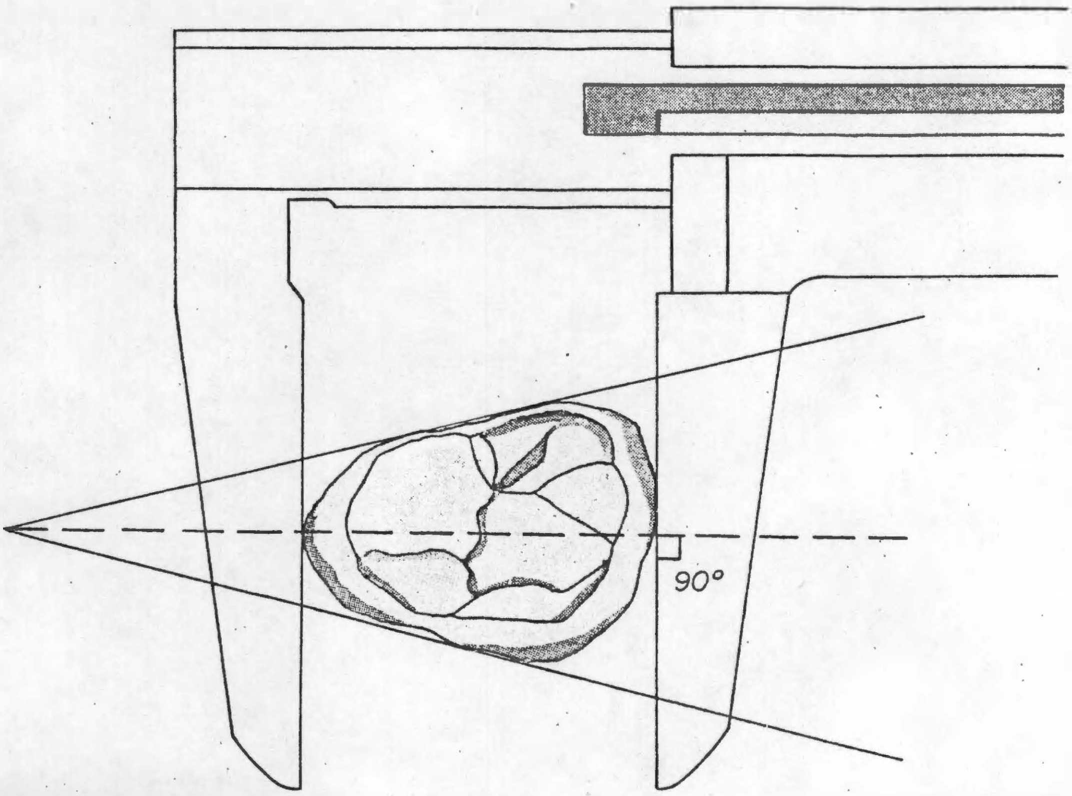

Figure 2. Occlusal view of the measurement of a maxillary molar. The solid lines are passing through the estimated mesial and distal surface planes. The dotted line bisects the angle formed by these lines.

Teeth excluded from the analysis were:

1. Those that could not be associated with a burial number.

2. Those too heavily worn to identify necessary landmarks.

3. Those in which occlusal wear had erased the points of maximum breadth.

4. Those set in the alveolus in such a way that the caliper arms could not reach the points of maximum breadth.

5. Supernumary teeth.

CHAPTER IV

STATISTICAL METHODS

The measurements were stored on a disc in the DEC-System 10 computer system of The University of Tennessee, Knoxville. This storage process was greatly facilitated by using the program, TEETH.FOR, a data entering FORTRAN program written for the project by Mr. William Baden. All statistical analyses were done with the DEC-System 10 or the IBM 370/3031. Descriptive statistics are given in Tables 1-3.

Two statistical approaches were used to examine the patterning of fluctuating dental asymmetry. Correlation coefficients were computed for the measurements of antimeric pairs of teeth. Groups of burials were then compared for significant differences in the coefficients for each pair of teeth. In the second approach, analysis of variance was employed to reveal the pattern of variation among groups in the absolute difference of left and right tooth measurements. Bader (1965) used both of these statistical methods to search for differences in dental asymmetry of four lines of mice (inbred, hybrid, randombred, and wild). He had more success with the correlation coefficients, though results from the two methods were compatible.

Pearson Correlation Coefficients

The subprogram, PEARSON CORR, of the Statistical Package for the Social Sciences (Nie et al., 1975) was used to compute correlation coefficients for all antimeric pairs of measurements for all teeth of each subgroup defined for this project. Higher coefficients indicate

TABLE 1. Descriptive Statistics of Bucco-Lingual Diameters of Male Teeth (in millimeters).

Tooth	N	Mean	S.D.	Range	Skewness	Kurtosis
Lowers						
I_1	104	5.755	0.331	5.1- 6.7	0.497	0.115
I_2	134	6.181	0.311	5.5- 7.0	-0.065	-0.155
C	182	7.860	0.432	6.9- 9.3	0.153	-0.052
P_1	160	8.110	0.402	7.1- 9.6	0.526	1.034
P_2	142	8.420	0.444	7.4-10.0	0.610	0.901
M_1	124	11.071	0.490	10.0-12.2	0.330	-0.201
M_2	140	10.603	0.592	9.4-12.9	0.709	0.866
M_3	124	10.540	0.606	8.8-12.5	0.370	0.836
Uppers						
I_1	78	7.286	0.437	6.5- 8.4	0.373	0.008
I_2	90	6.620	0.471	5.6- 7.9	0.178	-0.202
C	125	8.672	0.491	7.7-10.1	0.483	0.513
P_1	122	9.660	0.542	8.3-11.3	0.373	0.349
P_2	111	9.583	0.532	8.2-11.3	0.415	0.498
M_1	115	12.086	0.529	10.9-13.6	0.309	0.578
M_2	123	11.811	0.643	10.5-14.0	0.838	1.387
M_3	78	11.142	0.811	8.3-14.2	0.286	3.072

TABLE 2. Descriptive Statistics of Bucco-Lingual Diameters of Female Teeth (in millimeters).

Tooth	N	Mean	S.D.	Range	Skewness	Kurtosis
Lowers						
I_1	86	5.536	0.319	5.0- 6.3	0.606	-0.305
I_2	112	5.996	0.312	5.2- 6.8	0.106	0.725
C	164	7.316	0.423	6.2- 8.7	-0.105	0.933
P_1	154	7.879	0.492	6.7- 9.1	0.047	-0.169
P_2	136	8.270	0.494	6.6- 9.4	-0.298	0.904
M_1	118	10.825	0.451	9.7-11.7	-0.088	-0.419
M_2	128	10.303	0.545	9.2-11.9	-0.428	-0.027
M_3	118	10.246	0.645	8.1-12.1	-0.008	1.041
Uppers						
I_1	80	7.050	0.350	6.1- 7.9	-0.056	-0.199
I_2	86	6.483	0.560	4.7- 8.1	-0.420	2.157
C	121	8.107	0.495	6.9-10.1	0.526	1.709
P_1	96	9.586	0.562	8.0-11.7	0.350	1.633
P_2	111	9.408	0.605	8.0-10.8	-0.035	-0.461
M_1	125	11.738	0.597	10.2-13.1	-0.111	-0.184
M_2	137	11.336	0.603	9.8-13.2	0.228	0.294
M_3	90	10.816	0.788	9.3-13.7	1.079	2.006

TABLE 3. Descriptive Statistics of Bucco-Lingual Diameters of Deciduous Teeth (in millimeters).

Tooth	N	Mean	S.D.	Range	Skewness	Kurtosis
Lowers						
I_1	90	3.810	0.224	3.4- 4.4	-0.042	-0.576
I_2	124	4.258	0.266	3.5- 5.0	0.031	0.780
C	162	5.467	0.315	4.6- 6.2	-0.291	-0.358
M_1	254	7.839	0.553	6.3- 9.7	0.112	0.544
M_2	266	9.291	0.454	8.0-11.0	0.723	1.983
Uppers						
I_1	104	5.092	0.378	4.4- 6.5	0.835	1.833
I_2	98	4.935	0.334	3.7- 5.8	-0.552	1.816
C	124	5.952	0.426	4.8- 7.0	-0.001	-0.275
M_1	182	9.036	0.449	7.3-10.3	-0.343	1.123
M_2	206	10.418	0.459	9.3-11.7	0.139	-0.132

higher degrees of similarity between two teeth within a group and thus more symmetry. To test for significant differences in asymmetry between two groups, the Fisher's Z transformation was used (Hays, 1973: 662-665). To use this test, the coefficient of each group to be compared must first be converted to Z scores by the following formula:

$$Z_1 = \tfrac{1}{2}\log_e \left(\frac{1 + r}{1 - r}\right)$$

where r is the correlation coefficient, and Z_1 is the resulting Z score for Group 1. The standard deviation of $Z_1 - Z_2$ must then be computed by the following formula:

$$\sigma(Z_1 - Z_2) = \frac{1}{N_1 - 3} + \frac{1}{N_2 - 3}$$

where N_1 and N_2 are the sample sizes of the two groups, respectively. The Fisher's Z test is executed by the following formula:

$$Z = \frac{Z_1 - Z_2}{\sigma(Z_1 - Z_2)}$$

The probability that Groups 1 and 2 differ can be found in any normal probability table for the corresponding Z value calculated above. If Z is positive, Group 1 is more symmetrical for the tooth in question. The reverse is true if Z is negative. I have chosen 0.05 as the level of significance for all statistical tests.

In line with the stated purposes of this thesis (pp. 3-4), the following comparisons were made:

1. Each cemetery with every other for each pair of permanent teeth where (a) each sex was considered separately and (b) the sexes were pooled.

2. Males with females for each pair of teeth, cemeteries pooled.

3. Permanent against deciduous teeth for incisors and canine pairs only.

For the cemetery comparisons, tests were done for each sex separately to see if one sex was more responsible than the other for cemetery differences. When comparing the permanent and deciduous dentitions, only incisors and canines were used because of the lack of correspondence of elements between the two dentitions posterior to the canines.

Analysis of Variance

One analysis of variance (ANOVA) was done for each pair of teeth. For all ANOVAs the dependent variable used was the unsigned difference between the left and right tooth measurements. For reasons discussed in Chapter II, I felt it was necessary to check for a scaling effect of tooth size on the side differences. If such an effect is found, it would be necessary to adjust for tooth size before calculating the side differences to be used in the ANOVAs.[1]

To see if tooth size affects asymmetry, the absolute value of left minus right measurements was regressed against the mean of the left and right measurements. This was done for all pairs of permanent and deciduous teeth in the sample. Regression analyses were done

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[1] No size adjustment is needed when using correlation coefficients. Each sides' measurement would be equally affected, and the relationship of measurements between the sides would remain the same within the population.

with the REGRESSION subprogram of the Statistical Package for the Social Sciences (Nie et al., 1975). Results of all regression analyses are presented in Tables 4-7.

The significance of these results will be discussed in more detail later. Suffice it to say here that adjustments should be made for tooth size before ANOVAs are attempted. Otherwise it would be impossible to determine whether a difference in developmental stability or tooth size was responsible for observed asymmetry differences between the groups compared.

In order to correct for tooth size, all raw measurements were converted to Z scores using Option 3 of the SPSS subprogram, CONDESCRIPTIVE. Z scores are calculated as follows:

$$Z = \frac{X_i - \overline{X}}{\sigma}$$

where X_i is the measurement being converted, $\overline{X}$ is the mean of that variable, and σ is the standard deviation of that variable. Conversion to Z scores accomplished the desired adjustments by putting all measurements into terms of standard deviation. Thus, if a permanent lower first molar ranks at the 90th percentile for size of that tooth in the population, and a deciduous upper lateral incisor ranks at the 90th percentile for size of that tooth, each will have the same Z score. It can be seen that comparisons across sexes, across tooth types, or across dentition types, can be made without the fear of size influencing asymmetry values.

Analysis of variance can determine if one or more independent variables has a significant influence on a dependent variable. For example, sex was used as an independent variable. It, of course,

TABLE 4. Regression Coefficients of the Absolute Value of Left Minus Right Tooth Diameters with Mean Tooth Size, Male Teeth.

Tooth	Coefficient	F Value	Probability[a]
Lowers			
I_1	-0.03335	0.05680	-------
I_2	0.14328	1.40433	-------
C	0.00998	0.00897	-------
P_1	0.16016	2.10604	-------
P_2	0.13940	1.40704	-------
M_1	-0.06240	0.24232	-------
M_2	0.37382	11.37066	$P < 0.005$
M_3	0.01773	0.01950	-------
Uppers			
I_1	0.07583	0.21977	-------
I_2	0.05808	0.14893	-------
C	-0.29392	5.76787	$P < 0.025$
P_1	-0.02528	0.03902	-------
P_2	0.01473	0.01193	-------
M_1	0.01024	0.00598	-------
M_2	0.00904	0.00457	-------
M_3	0.15542	0.96538	-------

[a] Listed only where $P < 0.05$.

TABLE 5. Regression Coefficients of the Absolute Value of Left Minus Right Tooth Diameters with Mean Tooth Size, Female Teeth.

Tooth	Coefficient	F Value	Probability[a]
Lowers			
I_1	-0.05002	0.10286	-------
I_2	0.10003	0.54578	-------
C	-0.16055	2.11671	-------
P_1	0.01963	0.02890	-------
P_2	-0.05074	0.17036	-------
M_1	-0.14630	1.24674	-------
M_2	0.03861	0.09257	-------
M_3	0.22452	3.02594	-------
Uppers			
I_1	-0.24438	2.41366	-------
I_2	-0.13130	0.71924	-------
C	-0.14547	1.27552	-------
P_1	0.03885	0.06954	-------
P_2	-0.09288	0.46988	-------
M_1	-0.11990	0.88979	-------
M_2	0.53459	26.81018	$P < 0.001$
M_3	0.42826	9.65805	$P < 0.005$

[a] Listed only where $P < 0.05$.

TABLE 6. Regression Coefficients of the Absolute Value of Left Minus Right Tooth Diameters with Mean Tooth Size, Sexes Pooled.

Tooth	Coefficient	F Value	Probability[a]
Lowers			
I_1	-0.05443	0.27935	-------
I_2	0.17975	4.10668	$P < 0.050$
C	0.01366	0.03209	-------
P_1	0.10414	1.72124	-------
P_2	0.01924	0.05150	-------
M_1	-0.11294	1.56345	-------
M_2	0.28939	12.24750	$P < 0.001$
M_3	0.06697	.54521	-------
Uppers			
I_1	-0.09846	0.76354	-------
I_2	-0.01200	0.01254	-------
C	-0.28361	10.67136	$P < 0.005$
P_1	-0.00497	0.00270	-------
P_2	-0.02313	0.05942	-------
M_1	-0.08606	0.89535	-------
M_2	-0.08591	0.88487	-------
M_3	0.28123	7.21409	$P < 0.010$

[a] Listed only where $P < 0.05$.

TABLE 7. Regression Coefficients of the Absolute Value of Left Minus Right Tooth Diameters with Mean Tooth Size, Deciduous Teeth.

Tooth	Coefficient	F Value	Probability[a]
Lowers			
I_1	0.26237	3.32662	-------
I_2	0.07484	0.36617	-------
C	-0.13464	1.53235	-------
M_1	0.31679	14.61302	$P < 0.001$
M_2	0.23668	7.89265	$P < 0.010$
Uppers			
I_1	0.07181	0.26952	-------
I_2	-0.03650	0.06672	-------
C	0.05628	0.20018	-------
M_1	-0.09884	0.90759	-------
M_2	0.02648	0.07087	-------

[a] Listed only where $P < 0.05$.

has two "levels"--male and female. A dependent variable used was lower canine asymmetry as measured by the unsigned difference between the left and right Z scores. By using an F test, ANOVA can determine if there is a significant difference between the two levels of sex in the dependent variable. The F test employs the F ratio, which is calculated as follows:

$$F = \frac{\text{MS between}}{\text{MS within}}$$

MS between is a measure of the variation between the sexes in lower canine asymmetry. MS within is a measure of variation within the pooled sexes. A very high F ratio would indicate that there is much more variation between the sexes than there is among adults in general. An F distribution table is used to see if the F ratio is high enough to conclude that the differences between the sexes (levels) is statistically significant at the 0.05 level.[2]

An advantage of ANOVA is that the influence of more than one independent variable on the dependent variable may be tested simultaneously. For instance, if partial sums of squares are used in the F tests, then one can test for sex effects above and beyond the effect of cemetery number. To clarify this by an example, suppose that Cemetery 1 was composed mostly of males and Cemetery 2 mostly of females. A simple ANOVA, using only cemetery numer as an independent variable, might indicate that cemetery number had a significant effect on dental asymmetry (the dependent variable). We can see that cemetery differences may actually be only sex differences. However,

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[2] See Sokal and Rohlf (1969:175-202) for an explanation of sums of squares (SS) and proper use of the F distribution table.

an ANOVA using both sex and cemetery number as independent variables can tell us if either or both have an effect on asymmetry. The use of partial sums of squares in the F test for each effect will control for all other effects used in the model.[3]

In addition, ANOVA allows a test for influence of interaction between two independent variables upon the dependent variable. In other words, cemetery number and sex may covary through the Averbuch population in such a way that their interaction has a significant affect on dental asymmetry. It would be difficult to interpret the meaning of the interaction. Nonetheless, if interaction exists, it too may have a misleading effect on cemetery number or sex. Again, if this interaction is part of the ANOVA model then use of partial SS will adjust for its influence.

All ANOVAs were done with the GLM procedure of SAS 76 (Barr et al., 1976). The following models were run, once for each pair of teeth.

1. Asymmetry of the permanent teeth as the dependent variable, sexes pooled; the independent variables were cemetery number, sex, and cemetery number-sex interaction.

2. Asymmetry of the deciduous teeth as the dependent variable; the independent variable was cemetery number.

3. 1 and 2, above, using only Cemeteries 1 and 3.

The ANOVAs in 3 above, were done because the sample sizes from Cemetery 2 were often too small. It was also desirable to test Cemeteries 1 and 3 alone because of their suspected temporal relationship.

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[3] See Barr et al., (1976:315-316) for a mathematical explanation of partial sums of squares.

CHAPTER V

RESULTS

Analysis of Correlation Coefficients

In the tables reporting the correlation coefficients, a positive Z ratio indicates that there is more symmetry in the group presented in the upper part of the table than the lower part. The level of significance chosen was $P < 0.05$.

For pooled sex comparisons of permanent teeth, Cemetery 1 is more symmetrical than Cemetery 2 for the lower second premolar (Table 8). Cemetery 3 is more symmetrical than Cemetery 1 for the mandibular first premolar and first molar (Table 9), and for the maxillary lateral incisor and first molar (Table 10). Cemetery 3 is more symmetrical than Cemetery 2 for the lower canine and both premolars (Table 11). It appears that the adults of Cemetery 3 are the most symmetrical and those of Cemetery 2 the least. This pattern is supported by the signs accompanying the nonsignificant Z ratios of Tables 8-11.

When sexes are considered separately, the only permanent tooth with sufficient sample size from Cemetery 2 is the male lower canine. There is no difference in asymmetry for this tooth between Cemeteries 1 and 2 (Table 12). The relationship between Cemeteries 1 and 3 is the same as when sexes are pooled. Cemetery 3 males have more symmetrical lower first premolars than Cemetery 1 males (Table 13). No other teeth from Cemetery 3 males had an adequate sample size. Cemetery 3

TABLE 8. Comparison of Correlation Coefficients between Paired Teeth of Cemetery 1 and Cemetery 2. Permanent Teeth, Sexes Pooled.[a]

Tooth Pair	Lower C	Lower P1	Lower P2	Lower M2	Upper C
Cem. 1					
N	111	95	88	84	73
r	0.9326	0.7992	0.8625	0.8939	0.9287
Z transform	1.6780	1.0964	1.3030	1.4410	1.6489
Cem. 2					
N	29	24	19	19	20
r	0.8788	0.7559	0.5409	0.8313	0.9622
Z transform	1.3705	0.9866	0.6054	1.1923	1.9748
$\sigma(Z_1 - Z_2)$	0.2185	0.2418	0.2725	0.2730	0.2704
Z ratio	1.4073	0.4541	2.5600[b]	0.9110	-1.2053

[a] Pairs with inadequate sample sizes are not given.

[b] Probability 0.01.

TABLE 9. Comparison of Correlation Coefficients between Permanent Mandibular Paired Teeth of Cemetery 1 and Cemetery 3, Sexes Pooled.

Tooth Pair	I1	I2	C	P1	P2	M1	M2	M3
Cem. 1								
N	53	76	111	95	88	81	84	81
r	0.9380	0.9007	0.9326	0.7992	0.8625	0.9069	0.8939	0.5843
Z transform	1.7211	1.4759	1.6780	1.0964	1.3030	1.5089	1.4410	.6690
Cem. 3								
N	26	31	33	38	32	28	31	28
r	0.9534	0.9037	0.9637	0.9417	0.9141	0.9682	0.8573	0.6224
Z transform	1.8679	1.4920	1.9954	1.7529	1.5519	2.0627	1.2831	0.7289
$\sigma(Z_1 - Z_3)$	0.2519	0.2223	0.2064	0.1986	0.2151	0.2298	0.1890	0.2298
Z ratio	-0.5828	-0.0724	-1.5378	-3.3056[b]	-1.1697	-2.4060[a]	0.8354	-0.2607

[a] Probability < 0.020.

[b] Probability < 0.001.

TABLE 10. Comparison of Correlation Coefficients between Permanent Maxillary Paired Teeth of Cemetery 1 and Cemetery 3, Sexes Pooled.

Tooth Pair	I1	I2	C	P1	P2	M1	M2	M3
Cem. 1								
N	51	55	73	65	71	73	81	53
r	0.8771	0.7612	0.9287	0.8561	0.9177	0.8972	0.8799	0.6235
Z transform	1.3631	0.9991	1.6489	1.2786	1.5743	1.4577	1.3753	0.7307
Cem. 3								
N	19	24	30	29	27	35	34	21
r	0.9330	0.9420	0.9315	0.8857	0.8858	0.9740	0.8908	0.5526
Z transform	1.6811	1.7555	1.6696	1.4016	1.4021	2.1649	1.4258	0.6221
$\sigma(Z_1 - Z_3)$	0.2887	0.2586	0.2265	0.2336	0.2374	0.2134	0.2123	0.3951
Z Ratio	-1.1015	-2.9250[a]	-0.0914	-0.5265	0.7254	-3.3140[b]	-0.2379	0.3108

[a] Probability < 0.005.

[b] Probability < 0.001.

TABLE 11. Comparison of Correlation Coefficients between Permanent Paired Teeth of Cemetery 2 and Cemetery 3, Sexes Pooled.[a]

Tooth Pair	Lower C	Lower P1	Lower P2	Lower M2	Upper C
Cem. 2					
N	29	24	19	19	20
r	0.8788	0.7559	0.5409	0.8313	0.9622
Z transform	1.3705	0.9866	0.6054	1.1923	1.9748
Cem. 3					
N	33	38	32	31	30
r	0.9637	0.9417	0.9141	0.8573	0.9315
Z transform	1.9954	1.7529	1.5519	1.2831	1.6696
$\sigma(Z_2 - Z_3)$	0.2679	0.2760	0.3114	0.3134	0.3096
Z ratio	-2.3326[b]	-2.7764[c]	-3.0395[c]	-0.2897	0.9859

[a] Pairs with inadequate sample sizes are not given.

[b] Probability 0.020.

[c] Probability 0.005.

TABLE 12. Comparison of Correlation Coefficient between the Permanent Lower Canines of Cemetery 1 and Cemetery 2 Males.[a]

	Cem. 1			Cem. 2			
N	r	Z transform	N	r	Z transform	$\sigma(Z_1 - Z_2)$	Z ratio
58	0.8976	1.4597	20	0.8929	1.4360	0.2775	0.0854[b]

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[a] All other tooth pairs from Cemetery 2 had inadequate sample sizes.

[b] Not significant.

TABLE 13. Comparison of Correlation Coefficient between the Permanent Lower First Premolars of Cemetery 1 and Cemetery 3 Males.[a]

	Cem. 1			Cem. 2			
N	r	Z transform	N	r	Z transform	$\sigma(Z_1-Z_3)$	Z ratio
44	0.7289	0.9264	19	0.9163	1.5655	0.2948	-2.1679[b]

[a] All other tooth pairs from Cemetery 3 had inadequate sample sizes.

[b] Probability < 0.05.

females have more symmetrical lower first premolars and upper first molars than Cemetery 1 females (Table 14).

The deciducus teeth indicate the same relationship between Cemeteries 1 and 3, but more strongly. Cemetery 3 lower first molars and all upper teeth are significantly more symmetrical than for Cemetery 1 (Table 15). The sample size for deciduous teeth from Cemetery 2 are inadequate for comparison.

For comparisons of the adult sexes in Tables 16 and 17, females are more symmetrical than males for the lower first premolar and second molar, and the upper lateral incisor and second premolar. Surprisingly the male upper canines are significantly more symmetrical than for females. The randomness of the patterns of the signs accompanying the Z ratios in Tables 16 and 17 are difficult to interpret. However, the hypothesis that Averbuch females are more dentally symmetrical than males is supported by these data.

Table 18 shows that there are significant differences in asymmetry in every deciduous and permanent tooth compared. Curiously, deciduous teeth are more symmetrical for the upper incisors, while the permanent teeth are more symmetrical for the upper canines and all three lower anterior teeth.

Analysis of Variance

Only ANOVA tables of teeth showing significant or nearly significant results ($P < 0.05$) for one or more effects are presented in this section.

Table 19 shows that the interaction of sex and cemetery number significantly affects lower lateral incisor asymmetry. This

TABLE 14. Comparison of Correlation Coefficients of Permanent Female Tooth Pairs between Cemetery 1 and Cemetery 3.[a]

	Lower C	Lower P1	Upper M1	Upper M2
Cem. 1				
N	53	51	35	40
r	0.9240	0.8203	0.8883	0.8790
Z transform	1.6157	1.1527	1.4138	1.3714
Cem. 3				
N	20	19	22	21
r	0.9406	0.9603	0.9657	0.8790
Z transform	1.7472	1.9498	2.0242	1.3714
$\sigma(Z_1-Z_3)$	0.2808	0.2887	0.2896	0.2874
Z ratio	-0.4541	-2.7610[c]	-2.1077[b]	-1.3772

[a] All other tooth pairs from Cemetery 3 had inadequate sample sizes.

[b] Probability < 0.05.

[c] Probability < 0.01.

TABLE 15. Comparison of Correlation Coefficients between Deciduous Paired Teeth of Cemetery 1 and Cemetery 3.[a]

Tooth Pair	Lower I2	Lower C	Lower M1	Lower M2	Upper I1	Upper I2	Upper C	Upper M1	Upper M2
Cem. 1									
N	35	53	78	85	28	24	36	48	62
r	0.7769	0.8023	0.8590	0.9353	0.9335	0.9360	0.7549	0.8783	0.8860
Z transform	1.0375	1.1050	1.2895	1.6991	1.6849	1.7047	0.9843	1.3683	1.4030
Cem. 3									
N	21	19	34	32	23	22	21	34	26
r	0.8879	0.9031	0.9818	0.9148	0.9825	0.9974	0.9642	0.9924	0.9954
Z transform	1.4119	1.4888	2.3452	1.5562	2.3650	3.3220	2.0024	2.7845	3.0363
$\sigma(Z_1 - Z_3)$	0.2946	0.2872	0.2135	0.2157	0.3000	0.3166	0.2930	0.2334	0.2458
Z ratio	-1.2709	-1.3364	-4.9473[c]	0.6625	-2.670[b]	-5.1083[c]	-3.4747[c]	-6.0677[c]	-6.6502[c]

[a] The sample size of Cemetery 3 lower I1 is too small for comparison.

[b] Probability < 0.010.

[c] Probability < 0.001.

TABLE 16. Comparison of Correlation Coefficients between Permanent Mandibular Paired Teeth of Males and Females.

Tooth Pair	I1	I2	C	P1	P2	M1	M2	M3
Males								
N	52	68	92	81	72	63	71	63
r	0.9454	0.8706	0.8869	0.7228	0.8346	0.9418	0.7998	0.5403
Z transform	1.7866	1.3356	1.4072	0.9135	1.2031	1.7537	1.0981	0.6046
Females								
N	43	56	82	77	68	59	64	59
r	0.9270	0.9261	0.9239	0.8852	0.7762	0.8862	0.9187	0.7417
Z transform	1.6366	1.6303	1.6150	1.3993	1.0357	1.4039	1.5806	0.9542
$\sigma(Z_m - Z_f)$	0.2131	0.1851	0.1551	0.1623	0.1729	0.1858	0.1764	0.1858
Z ratio	0.7039	-1.5921	-1.3398	-2.9932^{b}	0.9682	1.8826	-2.7353^{a}	-1.8816

[a] Probability < 0.010.

[b] Probability < 0.005.

TABLE 17. Comparison of Correlation Coefficients between Maxillary Paired Teeth of Males and Females.

Tooth Pair	I1	I2	C	P1	P2	M1	M2	M3
Males								
N	40	46	63	62	56	58	62	40
r	0.9344	0.7736	0.9436	0.8389	0.8731	0.9259	0.8474	0.6004
Z transform	1.6920	1.0292	1.7699	1.2174	1.3460	1.6289	1.2469	0.6938
Females								
N	40	43	61	48	56	63	69	45
r	0.8513	0.9077	0.8824	0.8596	0.9402	0.9125	0.8864	0.6181
Z transform	1.2606	1.5143	1.3865	1.2918	1.7398	1.5423	1.4049	0.7291
$\sigma(Z_m - Z_f)$	0.2325	0.2197	0.1841	0.1979	0.1943	0.1867	0.1792	0.2255
Z ratio	1.8555	-2.2080[a]	2.0826[a]	-0.3759	-2.0268[a]	0.4638	-0.8817	-0.1246

[a] Probability < 0.050.

TABLE 18. Comparison of Correlation Coefficients between Paired Teeth of Permanent and Deciduous Incisors and Canines.

Tooth Pair	Lower I1	Lower I2	Lower C	Upper I1	Upper I2	Upper C
Deciduous						
N	47	66	84	54	52	64
r	0.8452	0.8231	0.8487	0.9354	0.9035	0.8547
Z transform	1.2391	1.1664	1.2515	1.6999	1.4910	1.2733
Permanent						
N	95	124	174	80	89	124
r	0.9423	0.9037	0.9320	0.9109	0.8520	0.9344
Z transform	1.7582	1.4920	1.6734	1.5328	1.2634	1.6920
$\sigma(Z_d - Z_p)$	0.1833	0.0241	0.0182	0.0326	0.0320	0.0247
Z ratio	-2.8320[a]	-13.5104[a]	-23.1813[a]	5.1258[a]	7.1125[a]	-16.9514[a]

[a] Probability < 0.005.

TABLE 19. Analysis of Variance of Permanent Mandibular Lateral Incisor Asymmetry for Three Cemeteries. Error D.F. = 117.

Effect and Groups[a]	Group Mean Asymmetry	Partial S.S.	D.F.	F Ratio
Cemetery		0.0023	2	0.15
Sex		0.0133	1	1.72
Cem. by Sex		0.0544	2	3.53[b]
Cem. 1 males	0.1594			
Cem. 1 females	0.0924			
Cem. 2 males	0.1361			
Cem. 2 females	0.0880			
Cem. 3 males	0.1041			
Cem. 3 females	0.1363			

[a] Listed only where effect is significant.

[b] Probability < 0.05.

interaction becomes more significant when Cemetery 2 is excluded from the analysis (Table 20).

The cemetery-sex interaction also has a nearly significant effect on asymmetry of the lower first premolar (Table 21). When Cemetery 2 is excluded from the analysis, the interaction loses its significance but cemetery number becomes important (Table 22). The mean asymmeteries for this tooth agree with the correlation analysis of Table 9 (p. 34); they indicate that Cemetery 3 is more symmetrical than Cemetery 1.

Cemetery number has a highly significant effect on the asymmetry of the mandibular second premolar. Table 23 shows that Cemeteries 1 and 3 have very nearly the same amounts of asymmetry for this tooth while the mean side difference for Cemetery 2 is much higher. This agrees with the information in Tables 9-11 (pp. 34-36). Table 23 also shows that males are nearly significantly more symmetrical than females, a possibility that is not upheld in the correlation analysis of Table 16 (p. 42). Finally, Table 23 shows that cemetery-sex interaction has an effect on mandibular second premolar asymmetry.

When Cemeteries 1 and 3 are considered without Cemetery 2 in the model, the cemetery-sex interaction has a significant effect on permanent lower first molar asymmetry (Table 24). Asymmetry of the permanent maxillary first molars differs between Cemeteries 1 and 3, with Cemetery 1 being more symmetrical (Table 25). This agrees with the correlation analysis of Table 10 (p. 35).

None of the ANOVAs of deciduous teeth produced significant results. This is surprising in light of clear differences between Cemeteries 1 and 3 shown in Table 15 (p. 41).

TABLE 20. Analysis of Variance of Permanent Mandibular Lateral Incisor Asymmetry for Cemetery 1 and Cemetery 3. Error D.F. = 103.

Effect and Groups[a]	Group Mean Asymmetry	Partial S.S.	D.F.	F Ratio
Cemetery		0.0006	1	0.06
Sex		0.0078	1	0.88
Cem. x Sex		0.0655	1	7.41[b]
Cem. 1 males	0.1614			
Cem. 1 females	0.0880			
Cem. 3 males	0.1018			
Cem. 3 females	0.1375			

[a] Listed only where effect is significant below 0.05 level.

[b] Probability < 0.008.

TABLE 21. Analysis of Variance of Permanent Mandibular First Premolar Asymmetry for Three Cemeteries. Error D.F. = 151.

Effect and Groups[a]	Group Mean Asymmetry	Partial S.S.	D.F.	F Ratio
Cemetery		0.4881	2	1.40
Sex		0.5569	1	3.20
Cem. by Sex		1.0267	2	2.95[b]
Cem. 1 males	0.3820			
Cem. 1 females	0.4618			
Cem. 2 males	0.6168			
Cem. 2 females	0.2246			
Cem. 3 males	0.3552			
Cem. 3 females	0.2266			

[a] Listed only where effect is nearly significant at 0.050 level.

[b] Probability < 0.055.

TABLE 22. Analysis of Variance of Permanent Mandibular First Premolar Asymmetry for Cemetery 1 and Cemetery 3. Error D.F. = 129.

Effect and Groups[a]	Group Mean Asymmetry	Partial S.S.	D.F.	F Ratio
Cemetery		0.5019	1	4.04[b]
Cem. 1	0.4233			
Cem. 3	0.2845			
Sex		0.1042	1	0.08
Cem. x Sex		0.2404	1	1.94

[a] Listed only where effect is significant below 0.05 level.

[b] Probability < 0.05.

TABLE 23. Analysis of Variance of Permanent Mandibular Second Premolar Asymmetry for Three Cemeteries. Error D.F. = 133.

Effect and Groups[a]	Group Mean Asymmetry	Partial S.S.	D.F.	Ratio
Cemetery		3.8498	2	9.92[d]
Cem. 1	0.3498			
Cem. 2	0.7723			
Cem. 3	0.3440			
Sex		0.6657	1	3.43[b]
Males	0.3997			
Females	0.4130			
Cem. x Sex		1.4578	2	3.75[c]
Cem. 1 males	0.3716			
Cem. 1 females	0.3281			
Cem. 2 males	0.5368			
Cem. 2 females	1.1368			
Cem. 3 males	0.3544			
Cem. 3 females	0.3348			

[a] Listed only where effect is significant below 0.05 level.

[b] Probability < 0.0300.

[c] Probability < 0.0001.

[d] Probability < 0.0700.

TABLE 24. Analysis of Variance of Permanent Mandibular First Molar Asymmetry for Cemetery 1 and Cemetery 3. Error D.F. = 105.

Effect and Groups[a]	Group Mean Asymmetry	Partial S.S.	D.F.	F Ratio
Cemetery		0.0121	1	1.47
Sex		0.0043	1	0.52
Cem. x Sex		0.0299	1	3.63[b]
Cem. 1 males	0.0906			
Cem. 1 females	0.1142			
Cem. 3 males	0.1044			
Cem. 3 females	0.0522			

[a] Listed only where effect is nearly significant at 0.05 level.

[b] Probability < 0.06.

TABLE 25. Analysis of Variance of Permanent Maxillary First Molar Asymmetry for Cemetery 1 and Cemetery 3. Error D.F. = 104.

Effect and Groups[a]	Group Mean Asymmetry	Partial S.S.	D.F.	F Ratio
Cemetery		0.0496	1	3.71[b]
Cem. 1	0.1145			
Cem. 3	0.0696			
Sex		0.0026	1	0.20
Cem. x Sex		0.0002	1	0.02

[a] Listed only where effect is nearly significant at the 0.05 level.

[b] Probability < 0.06.

CHAPTER VI

DISCUSSION

There seems to be no relationship between Butler's (1939) field theory of tooth development on the one hand, and the patterning of asymmetry differences between groups on the other. The theory states that within a tooth class (e.g., molars) the more distal elements are less stable. One might expect the least stable teeth to better reflect group differences in stress. However, the random pattern throughout the mouth of significant group differences does not support this expectation. The results in Chapter V show the value of using as many kinds of teeth as possible when comparing groups for asymmetry differences.

The results from the analysis of correlation coefficients and the ANOVAs are consistent with each other, but the correlation coefficients showed greater distinction between groups in nearly all comparisons. This is surprising in view of the advantages of using partial sums of squares in ANOVA as pointed out in Chapter IV. It might be suggested that the "better" results from the r's are misleadingly attractive because only one effect was tested at a time, while the partial sums of squares correct for all effects but the one being tested, and thus, give a truer picture of the patterns of fluctuating dental asymmetry at Averbuch. I hesitate to accept this suggestion because ANOVAs using sequential sums of squares[1] showed

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[1] Sequential sums of squares were not used or reported because they would not have been as informative as partial sums of squares. See Barr et al. (1976:311) for a mathematical explanation of sequential sums of squares.

lower group differences for the effect entered into the model first than did partial sums of squares. For the purposes of this thesis, sequential sums of squares of the initial effect share some of the disadvantages of r's. Therefore, if r's showed misleadingly high group differences relative to partial sums of squares, the same would be expected of sequential sums of squares. This was not the case. I suggest that r's are a more sensitive measure of asymmetry and strongly suggest that both r's and ANOVAs be used in future studies of asymmetry.

The regression of left minus right measurements on tooth size demonstrated a relationship between those two variables for some teeth. Jantz (personal communication) has suggested the use of models other than simple linear regressions might clarify the exact relationship of the two variables, and it may be shown that tooth size affects asymmetry in other teeth as well.

It would be interesting to know why smaller upper canines are significantly more asymmetrical than larger ones, the opposite of what was expected. Canines, particularly the uppers, are known to be very developmentally stable teeth (Dahlberg, 1945; Bailit, 1975). It could be that those individuals with asymmetrical canines were very highly stressed during the time of canine crown formation. It is known that high levels of stress can result in decreased tooth dimensions as well as asymmetry (Bailit, 1975; DiBennardo, 1973; Garm et al., 1979). For Averbuch canines it might be that smaller teeth and higher asymmetry result from a common cause-disease, starvation, etc.. The obvious problem with this hypothesis is that one would then expect smaller teeth of all the other elements to also be more asymmetrical than their larger counterparts. Such is not the case. While the solution to this dilemma is not apparent, it has been shown that tooth size should be considered in asymmetry studies.

Though the hypothesis that females are more symmetrical than males is supported, the maxillary canine is again the exception. The male tooth may be more stable because of its presumed role in defense of the species before cultural weapons were developed (Brace, 1972). The reader should be warned not to attribute canine sexual dimorphism in asymmetry to dimorphism in tooth size. Tables 4 and 5 (pp. 26-27) show that the inverse relationship of size and asymmetry holds even within sexes.

It is encouraging to see that asymmetry of the deciduous teeth follows the same intercemetery patterning as for permanent teeth. The use of the two dentition types in conjunction, extends the life period of stress measurement from five months in utero to twelve years after birth (Schour and Massler, 1941). Other researchers are encouraged to incorporate deciduous teeth into asymmetry studies when possible.

There are two possible reasons that most of the deciduous teeth are significantly more asymmetrical than their permanent counterparts. One is that they may be inherently less resistant to stress (i.e. genetically "weaker"). The other possibility is that deciduous teeth from the Averbuch site belong to individuals who died early in life for the same reason that their teeth were more asymmetrical. Early death and asymmetry may both be due to severe prenatal stress and postnatal risk of disease (and presumably death). These two possibilities are, of course, not mutually exclusive.

Some help in choosing between the two explanations may be found by examining the only other report of asymmetry for both sets of teeth, that of Moorrees and Reed (1964). The authors calculated r's of all antimeres of a sample of white Americans but did not test for significant differences between permanent and deciduous teeth. I conducted Z tests on their published coefficients for all anterior teeth and found only one significant difference. The mandibular permanent lateral incisors were more symmetrical than their deciduous counterparts ($P < 0.001$). The fewer significant differences may be attributable to the fact that their younger sample of American whites was no more stressed than their older sample. It could then be said that the subadults from the Averbuch collection were more stressed than those that lived to adulthood. However, a word of caution is in order. Table 18 (p. 44) shows that the deciduous maxillary incisors were actually more symmetrical than the permanent maxillary incisors. To solve the problem, permanent-deciduous comparisons must be done for a living population of well known genetic and environmental backgrounds.

The archeologists who excavated the site have suggested one hypothesis to explain cemetery differences in fluctuating dental asymmetry (Klippel and Berryman, personal communication). As pointed out in Chapter I, the Middle Cumberland culture as a whole was characterized by fairly high population densities. It might be assumed that population pressure on food resources did not remain constant through the culture's span of existence (thirteenth through seventeenth centuries), but gradually increased with the passage of time. Whatever the reason for the demise of the Stone Box culture, it may be suggested that individuals living at and nearer the time of collapse were generally more "stressed" than their predecessors. The earlier members of the culture may have been living under conditions which more readily allowed societal growth without serious pressure on resources. At this time, the nature of the stresses can not be specified. However, the rat and human studies cited in Chapter II have shown dental asymmetry to be sensitive to a wide variety of stresses including nutritional deficiency. If these types of stresses accompanied the breakup of the culture, then the cemetery differences in asymmetry may be due to the fact that the more asymmetrical cemeteries date later.

Recall from Chapter I (p. 1) that diagnostic artifacts and the transection of Cemetery 3 by the stockade suggest that Cemetery 3 is earlier than Cemetery 1. As expected, Cemetery 3 shows less asymmetry than Cemetery 1. Cemetery 2, the most dentally asymmetrical, can not be dated.

If the cemeteries prove to be roughly contemporary, then the cemetery differences might reflect societal stratification. The more symmetrical individuals could have been children belonging to families of higher social rank. Although the Mississippian Period is characterized by the development of social stratification (Hudson, 1976:202-234), this latter hypothesis seems weaker than the former because there is no evidence indicating that stratification had reached levels found in modern societies. Of course, it is not known what levels of stratification would be necessary to influence fluctuating dental asymmetry.

It is possible to propose a mechanism by which cemetery differences were produced, regardless of what the cause of the differences is. Recall that the excessively worn teeth of older individuals were excluded from the measured sample. Also recall the suggested positive relationship between prenatal and early childhood stress and the later risk of disease and death (DiBennardo, 1973). These facts point out the tendency to systematically eliminate more stable or less stressed teeth from the analysis. Under the purportedly better living conditions of Cemetery 3, the stressed children had a better chance of living long enough to end up in the unmeasured part of the sample. Under the worsened conditions of Cemetery 1, a higher proportion of stressed children died young enough to still have measurable teeth.

A clearer understanding of the patterns of dental asymmetry at the Averbuch site awaits the completion of analysis of the cultural information recovered from the site. Exploration of the relationship of dental asymmetry to such factors as burial location and orientation, artifact associations, elaborateness of the stone box, and the number of persons per box is essential. Mr. Hugh E. Berryman is currently analyzing biological variables that are wholly or partly attributable to developmental environment: enamel hypoplasia, porotic hyperostosis; lines of arrested long bone growth, and long bone length. Knowing the relationship of dental asymmetry to these variables, and the relationship of all the biological stress variables to all the cultural variables of societal position will likely improve our understanding of both dental asymmetry and the Averbuch people as a whole.

I propose that the following adjustments be made in future studies of dental asymmetry of the site. Mesiodistal measurements should be used in addition to buccolingual, although this will greatly decrease sample sizes because only unworn teeth should be used. Siegel and Doyle (1975a) have shown that length and width of rat teeth are not always influenced in the same way by stress. In addition, estimates of occlusal area and shape of the occlusal surface probably carry much more developmental information than breadth alone.

I also recommend multivariate analyses of dental asymmetry. This too would significantly lower sample sizes, but if the analyses were limited to a small number of elements, perhaps one tooth from each class, the damage might not be too severe. Multivariate analyses of variance and coefficients of multiple correlation using breadth, length, crown shape, and occlusal area of several teeth would be particularly enlightening.

CHAPTER VII

CONCLUSIONS

It has been shown that the analysis of dental asymmetry is a valuable avenue of investigation for the bioculturally minded anthropologist. Although few specific statements can be made about the people of Averbuch at this point, a number of methodological suggestions can be made regarding the use of dental asymmetry to study archeological populations. First of all, asymmetry studies should be confined to within population comparisons as was done here. It is much more difficult to control for the factors of stress type, stress intensity, and the number of generations exposed to a stress when comparisons are made between populations coming from very different times and places. The genetic background of these varied groups is probably quite different, and natural selection may drastically alter a population's susceptibility to a given stress.

As in past studies of stress, sex is shown to be a factor that must be controlled for at Averbuch before group comparisons are made. Females are better able to resist stress and therefore tend to be more symmetrical with the exception of upper canines.

Researchers should also investigate the relationship of size on bilateral asymmetry. The relationship can be in either direction: larger teeth may be either more or less symmetrical than smaller teeth. If a relationship is found, an adjustment for tooth size may be necessary.

It has been shown that deciduous teeth carry enough information to justify their use in dental asymmetry research. Some of them are more asymmetrical than their permanent counterparts and some less so. Still, their intercemetery pattern of asymmetry follows that of the permanent dentition.

The skeletons from Cemetery 2 were found to be the most dentally asymmetrical and those of Cemetery 3 the least. Cemetery 1 is intermediate. These differences may reflect gradually increasing population pressures in the Nashville Basin. This suggestion would be more credible if it were found that Cemetery 3 is certainly older than Cemetery 1. Less likely, cemetery differences might represent social stratification or genetic differences in the ability to withstand stress. More definite suggestions to explain the patterning of fluctuating asymmetry at the Averbuch site await the analyses of archeological materials and other skeletal indicators of stress.

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