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Harris Lines as Indicators of Stress: An Analysis of Tibiae From the Crow Creek Massacre Victims

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To the Graduate Council:

I am submitting herewith a thesis written by Steven A. Symes entitled "Harris Lines as Indicators of Stress: An Analysis of Tibiae From the Crow Creek Massacre Victims." 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.

William M. Bass,, Major Professor

We have read this thesis and recommend its acceptance:

Richard Jantz, P. Willey

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

HARRIS LINES AS INDICATORS OF STRESS:
AN ANALYSIS OF TIBIAE FROM THE CROW CREEK MASSACRE VICTIMS

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

Steven A. Symes
August 1983

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We have read this thesis
and recommend its acceptance:

Willey

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

I dedicate this thesis to my parents.
Without their continual love and support
this would not have been possible.

ACKNOWLEDGEMENTS

While masters theses formally list only one author, numerous family members, colleagues and friends were instrumental in making this project possible. First and foremost, this thesis is dedicated to Ray and Mildred Symes, my parents. I offer this small tribute in exchange for more years of love and support than I can appreciate.

I first met Dr. William M. Bass in South Dakota in 1978. From that day on, Dr. Bass has supported me through the good and difficult times. This support has made this project and degree possible. My remaining committee members, Dr. Richard L. Jantz and Dr. P. Willey are also instrumental in this effort for their continued support, logic, and innovative ideas. I can only add that this thesis is simply a reflection of my committee's professional and personal guidance.

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instrumental in overseeing the actual radiographic process of Crow Creek Bones. Financial support for much of the Crow Creek data collection was supplied by the Research Committee of the School of Medicine, University of South Dakota.

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It is common knowledge that graduate students have to be taught practically everything. Because of this fact I have had to rely on three individuals well versed in the mechanics of this graduate system. Without the help of Dr. William M. Bass, Ms. Annette Blackbourne and Ms. Betty Spence I might still be standing in the Drop-Add line. Finally I would like to extend my most sincere thanks to Donna Blackbourne. Many know her only as Annette's daughter, but I have found her to be much more, thank you for your help.

ABSTRACT

Horizontal lines of increased density in bone, or Harris lines, have intrigued scientists for over a century. While earliest Harris line research dealt with medical aspects of line formation, most recent emphasis has been anthropological in nature, utilizing Harris lines as non-specific indicators of stress. The purpose of this study is to test the usefulness of Harris lines as they are applied anthropologically.

A sample of 122 adult distal tibiae x-rays are used in this study. This skeletal sample represents massacre victims from the Initial Coalescent Tradition of the Crow Creek Site in central South Dakota. Each bone was sexed by discriminant function analysis and age of line formation was estimated.

Harris line frequencies reveal no sex differences. However, when age-specific frequencies are compared with sex-specific human growth curves, there is a strong similarity in curve shape. These results suggest that sex influences on line formation are probably subtle but not detectable. The similarity in frequency of line formation and growth velocity has discouraging connotations for the usefulness of Harris lines as indicators of stress.

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CHAPTER I

INTRODUCTION

Since the introduction of x-rays, radiologists have commonly been aware of lines of increased density appearing in human bone. These bony lines are most commonly called lines of arrested growth or Harris lines after the extensive research on this topic by H. A. Harris (1926, 1931, 1933) near a half century ago. This phenomenon is the result of increased bone mineralization formed during bone growth. These lines have been of interest to medical researchers for some time since they represent immovable markers freezing that particular episode of growth and separating prior from subsequent growth.

The cause of Harris lines is a complex issue. The main thrust of etiological research concentrates on illness and nutritional influences on bone. Line formation is presumed to occur at growth resumption after a slow period. This variation in growth velocity is attributed to stresses that reach a threshold after which recovery occurs.

Anthropological application of Harris lines is fairly recent. Although a consistent one-to-one relationship between any stress and its bone marker is nonexistent, Harris lines and other nonspecific indicators of stress have become popular tools for understanding skeletal biology at the population level. Harris lines and other indicators of stress used in population approach research have been portrayed as the tools of the "new physical anthropology" (Buikstra and Cook, 1980).

The frequent use of Harris lines has not been without criticism. Like many indicators of stress, it is difficult to demonstrate a clear correspondence between illness or nutritional factors and Harris line formation. This biological phenomenon may be multicausal.

The use of Harris lines as indicators of stress and the anthropological inferences based upon Harris line analysis have raised many questions as to the validity of this type of research. This study addresses some of the issues by applying Harris line analysis to a particular skeletal sample. The results will focus on specific aspects of this type of research and hopefully shed some light on the overall utility of Harris lines as indicators of stress.

The following chapter reviews important issues in the last century of Harris line research. Not only does this review present the biology of Harris lines which is critical in confronting the problems raised by anthropology inferences, but it also raises many questions that are easily tested in a study such as this. Following the review of the literature is the formulation of hypotheses which outline the design of this research.

The material's chapter will introduce the archaeological site from which the skeletal sample originates. As well, descriptions of aging and sexing techniques will be addressed to present an accurate description of the skeletal sample used. The methods chapter will explain x-ray techniques, describe the physical characteristics that constitute a Harris line, and finally outline techniques used to assign ages to each transverse line. The results will outline patterns found in Harris lines by sex and finally the original hypotheses will be addressed and discussed in terms of the results found in the analysis.

CHAPTER II

HISTORY OF HARRIS LINE RESEARCH

Although anthropological interest in Harris lines is limited to the past, these bony lines have been a curiosity and topic of research for over a century (Wegner 1874; Gies 1877). Reviewing past literature is important to this study since it provides an improved understanding of Harris lines in general as well as shed light on implications for modern research. This chapter will examine Harris line histology, appearance, etiology, and finally uses and reliability.

Histology

Histological explanations for transverse Harris lines are quite simple. Long bone growth follows a cartilage perform. Bone is formed when osteoblasts settle into a logitudinal matrix frame provided by earlier cartilage growth. In the event growth is slowed or arrested, the osteoblasts settle on the horizontal undersurface of the epiphyseal plate that is perpendicular to the long axis. Instead of ossifying a longitudinal matrix, bone is horizontally arranged (Park 1954). Park (1954:277) likens this horizontal stratum to a line formed when epiphyseal closure begins and cartilage growth ends.

Although transverse lines begin to form with slowed cartilaginous growth, thickening of the stratum occurs with the resumption of normal growth. Revived growth triggers the cartilage maturation cycle and osteoblastic activity. However, until the cartilage life cycle is complete, no new matrix is available for ossification; thus osteoblasts cover the previous horizontal layer with more layers. Only when osteoblastic activity is allowed to break into longitudinal cartilage matrices, is the process of normal trabecular formation continued, ending Harris line formation. The remaining immovable structures are generally described as lattices or layers of horizontal bone strands. These layers of bone appear as transverse lines in x-ray because x-rays pass parallel to the plane of the bony layer (Park 1954:275-277).

For decades, scientists have been calling Harris lines "lines of arrested growth." This is derived from aberrant histological cartilage growth associated with line formation as described above. Although growth is slowed or even arrested at the histological level, there appears to be no correlation between line formation and the eventual length of the whole bone (Gindhart 1969). Thus the phrase "lines of arrested growth" refers only to histological cartilage development and not to growth in length of the whole bone.

Appearance

Harris lines vary in frequency and general appearance. While they may appear in all tubular bones and their epiphyses, Harris lines have been documented in many irregular bones as well (Garn, Silverman, et al. 1968. Lines in irregular bones often resemble, as Garn, Silverman et al. (1968:58) describe them, "elevation lines, topographically mapping the developmental history of the bone in question." Transverse lines occur most commonly in the distal tibia, followed by the proximal tibia, distal femur, distal humerus and metacarpals (Garn, Silverman, et al. 1968). Due to differential growth rates for each bone, lines vary in thickness from 1 millimeter to over 1 centimeter. Generally the thickest lines are at the ends of long bones, while near the midshaft lines are narrow and more transversely oriented (Steinbock 1976). Occasionally lines appear obliquely in tubular bone. These oblique lines normally do not span the complete diameter of the bone and occur most frequently in the medial aspect of the distal femur (Garn, Silverman, et al. 1968; Steinbock 1976).

Etiology

Understanding the etiology of transverse lines has proven difficult and complex. While there are specific causes of Harris line formation, most line formation appears to be multicausal. The only known specific cause for line formation is heavy metal absorption in the form of lead (Vogt 1932; Park et al. 1933; Caffey 1931), bismuth (Caffey 1937; Russin et al. 1942) and phosphorus or phosphorized cod liver oil administered for the sole purpose of forming transverse lines for the treatment of rickets (Wegner 1874; Phemister 1918; Adams 1938; Pease 1952). The literature is full of nonspecific factors suggested to influence Harris line formation. These include actinomycin D (Aarskog and Hexeberg 1968), directed pressure and tension on joint areas (Gelbke 1951), irradiation (Greulich and Pyle 1959), treatment of leukemia with aninopterin (Silverman 1950), prolonged exposure to x-rays (Hickle 1943), possible emotional disturbances (Sontag and Comstock 1938), and birth shock and maternal health (Sontag 1938; Sontag and Harris 1938).

While these factors very likely influence radiopaque line formation, the main thrust of research dealing with Harris line etiology involves illness and nutritional influences on bone. Fifty years ago, Harris (1933) listed measles, whooping cough, bronchopneumonia, influenza, laryngitis, chicken pox and diabetes as likely contributors to line formation. More recently, Garn, Silverman et al. (1968) recognized the problem of accurately relating episodes of disease to radiopaque lines in bone. Their solution to this problem involved gathering longitudinal radiographic data on children whose health was periodically reviewed. Garn and his colleagues found a significant but low order association between specific diseases (i.e. chicken pox, whooping cough, pneumonia and smallpox immunization) and line formation in the distal tibia. Gindhart (1969), in a similar study, also found high associations between disease and transverse lines but predictability of line generation was low.

Nutritional affects on growth were considered as early as 1924 when Asada (1924) produced transverse lines in starved laboratory rats. Similar studies using laboratory animals were also attempted by Acheson and MacIntyre (1958), Acheson (1959), Harris (1933), McCance et al. (1942), Platt and Stewart (1962), Stewart and Platt (1958), and Wolbach (1947). Kwashiorkor has been shown to produce lines in bones (Higginson 1954; Jones and Dean 1959), while Greulich and Pyle (1959:19-22) found undernourished children from Alabama produced lines when their diet was supplemented with reconstituted dry milk.

Inferential Uses and Reliability

As suggested earlier, Harris lines have a long history in medicine while anthropological Harris line research is recent. Medical scientists concerned with growth processes use Harris lines in two major areas of study: histopathologic growth and gross linear growth.

Histopathologic research simply explores mechanisms of line formation in bone microstructure. This is possibly the most common type of research using Harris lines (Harris 1926, 1931, 1933; Eliot et al. 1927; Follis and Park 1952; Park and Richter 1953; Park 1954, 1964; Acheson 1959). Linear growth research artificially produces or uses existing transverse lines as natural markers for radiographic monitoring of linear bone growth. These monitoring techniques are generally conducted to aid in treatment of asymmetrical limbs (Green and Anderson 1947; Pease 1952; Goff 1960).

An area of Harris line research that combines interest in medical and anthropological fields involves bone remodeling dynamics. Again Harris lines are used as natural markers, but in this type of research, relative growth and bone remodeling are of prime interest. Bone dynamics research produces allometric functions of relative bone growth for individual bones and joint areas (Garn, Silverman et al. 1968) and provide quantitative information for in vivo analysis of endosteal and subperiosteal apposition and resorption (Garn, Silverman et al. 1968; Garn, Hempy et al. 1968; Siegling 1941; Lee 1968). Simply stated, Harris lines combined with serial radiographs provide a means for monitoring bone growth and remodeling.

Anthropological interest in Harris lines as nonspecific indicators of stress generally involves illness and nutritional influences on bone. The first application of Harris lines in an anthropological study was conducted by Wells in 1961. Wells (1961, 1967) radiographically analyzed individuals from various prehistoric English populations and determined differential disease and nutritional influences not only between individuals but also between groups. McHenry (1968) also found significant differences in line formation in three temporally distinct samples of prehistoric American Indians in California. These frequency differences were interpreted as indications of nutritional status. These pioneering studies are important for demonstrating the potential of radiopaque transverse lines in anthropology. Similar studies have been attempted by Grey (1967), Woodall (1968), Allison, Mendoza and Pezzia (1974), Cook (1979), Cook and Buikstra (1979) and numerous others.

Most recently Harris line analysis has gone beyond simple inter-individual linecounts allowing some researchers to infer more than the degree of stress among individuals. McHenry (1968), Buikstra (1981), and Cook (1979) have suggested that Harris line data may demonstrate seasonal starvation in early groups of American Indians. Added information is gained when calculations of individual age at the time of line formation are performed. Numerous studies have attempted age estimations (Wells 1967, Allison et al. 1974; McHenry and Schultz 1976) but more recently these techniques have been revised (Hunt and Hatch 1981; Mensforth 1981) for greater accuracy.

While the use of Harris line data has become more sophisticated, identified problems have also increased. As mentioned, Garn and colleagues demonstrated disease-line associations but these studies also revealed that line formation was influenced by individual age and sex. Further complications arise when lines occur (approximately 10%) with no evidence of disease or trauma (Garn, Silverman et al. 1968).

Dreizen et al. (1964) found age-related associations influenced not only by disease, but also multi-complex factors:

> Factors which may have contributed to this age-related variation in scarring tendency in the distal radius are a decreased incidence and severity of infectious disease with increasing age, differences in the rate of linear growth of the radius from infancy through adolescence, and the hormonal changes associated with puberty (Dreizen et al. 1964:304).

In an earlier study, Dreizen et al. (1956:486) similarily reported "nutritional status _per se_ is not the determining factor in susceptibility to bone scar formation in growing children."

Almost all children at one time or another have visible transverse lines (Gindhart 1969) while their appearance in adults over 50 years may average only one line in four adults. Decrease in mineral density and bone remodeling are certainly major contributing factors to this differential appearance. Garn, Silverman et al. (1968) have shown that lines forming early in the distal tibia are susceptible to fading and early disappearance due to decreases in mineral density. However, lines forming later may be affected in a completely different manner. Bone apposition appears to be on the lateral side of the distal end of the tibia while bone resorption occurs on the medial aspect. Transverse lines subjected to this type of remodeling appear to shrink and drift medially (Garn, Silverman et al. 1968).

Finally it is important to remember that transverse line quantification and identification depends on each researcher's technique and the sample studied. Technique and bone orientation in x-ray may produce varied results due to age-related shrinkage of radiopaque lines. Variable results may also occur with x-rays of skeletal samples versus living individuals. As demonstrated above, growth studies have been essential in transverse line research, yet every researcher should realize that relative growth is by no means consistent. Medical records may also add bias since they are seldom as accurate as desired (Garn, Silverman et al. 1968).

CHAPTER III

HYPOTHESES

The preceding literature survey presents several questions which could be answered with further research. This project addresses three of those questions. These are listed below as hypotheses and are accompanied by short explanations.

Hypothesis I: Every remnant transverse Harris line represents a particular acute stress and recovery. Therefore it is possible to assume that Harris lines are valuable as anthropological tools in individual and population approach analysis.

Hypothesis I states that each Harris line chronologically etches, in the bone matrix, a recoverable stress encountered during the growing years of that bone. Therefore this radiographically observed marker indicates some type of stress and recovery that is age-specific, traceable to that particular time in the growth process. Thus Harris lines have the potential to reveal patterns within an individual (e.g. seasonal, etc.) or patterns within a group as a whole.

Hypothesis II: Frequency comparisons of Harris lines in a skeletal sample should produce observable sex differences.

Hypothesis II is logical because there are biological differences between the sexes and these differences should affect non-specific indicators of stress. The simple fact that boys grow at different rates than girls (Tanner 1978 and others) may also affect Harris line formation since these lines are created during the growing years.

Another difference commonly discussed in the literature is that boys are more susceptible to environmental stress than females. This would certainly suggest that boys form more lines than girls if all else is equal. And in fact, Gindhart (1969) in a longitudinal study has demonstrated that boys form more transverse lines than girls.

Hypothesis III: Since Harris line formation depends on a stress-related reduction or arrest of histological bone growth followed by recovery, overall growth velocity changes that occur predictably in all humans should affect the formation of these bony lines.

This final hypothesis is stimulated by a quote from Park almost 20 years prior to this study:

> Since growth, both cartilaginous and osteoblastic, is much more rapid in the first months of life, one might expect the widest distribution of arrest strata . . . in the young infant (Park 1964:833).

Extrapolations from this idea suggest that Harris line formation is affected by and depends upon growth velocity. This includes velocity changes throughout the growing years and not just one particular period. Therefore Hypothesis III tests the relationship between Harris line frequencies and the human growth curve.

The above hypotheses are based on an understanding of the history of Harris line research. Hypothesis I tests the utility of Harris line research. If lines do not represent individual stress and recovery, the applicability of Harris line analysis should be questioned. Hypotheses II and III suggest that sex and developmental age processes affect Harris line studies and must be controlled if an accurate analysis is expected. Before these hypotheses are tested, a description of the skeletal sample and methods used for analysis will be presented below.

CHAPTER IV

MATERIALS

The Crow Creek Site

A sample of adult tibia radiographs from the Crow Creek site in South Dakota are used in this analysis. The Crow Creek site (39BF11) is located on the east bluff of the Missouri River in central South Dakota. Although much of South Dakota is rich in prehistoric and historic cultural resources, the Crow Creek site has long been of intense interest to professional and amateur archaeologists. Much of this attention results from Crow Creek's most impressive and visible feature, an immense outer fortification ditch. W. H. Over, the premiere archaeologist of South Dakota, described the ditch as the "widest and deepest of any surrounding a village in the state" (Sigstad and Sigstad 1973:9). This ditch extends 1,250 feet (381 meters), has ten U-shaped bastions and is today about 15 feet (4.6 meters) across and six to 12 feet (1.8 to 3.7 meters) below ground surface of the village (Kivett and Jensen 1976).

Kivett and Jensen (1976:77-78) recognize three occupations at Crow Creek: Woodland, Initial Horizon of the Middle Missouri Tradition, and Initial Horizon of the Coalescent Tradition. All skeletal material used for this study is associated with the latter horizon, the Initial Coalescent Tradition. This tradition appears to be affiliated with Arikara tribes that temporally follows Crow Creek and inhabit the area into historic times (Willey 1982:1-2).

In 1978 human bones were observed protruding out of an eroding bank cutting into the site boundaries. What was planned as a routine excavation of a disturbed burial eventually grew into the systematic excavation and analysis of the largest known prehistoric massacre burial in North America with the greatest minimum element count totaling 486 individuals (Willey 1982). Public attention was again focused on the site in August, 1981 when the bones were reburied in the village site precluding any further analysis of the remains.

The Crow Creek skeletal sample is unique in that it is more than a sample, it is a sample with a normal demographic structure, all of morphologically similar individuals. Unfortunately this skeletal population in many ways lends less information to the researcher than do many cemetery samples. This is because most of the 486 plus individuals are commingled. Age- and sex-specific information is generally lacking due to few articulated bones. Since these factors are of utmost importance to this study, techniques for age and sex assessment of Crow Creek skeletal material are discussed below.

Degenerative Age Effects

Past studies dealing specifically with individual age and its effects on Harris line appearance and retention generally involve two types of age: developmental or degenerative. Developmental changes involve bone growth and growth velocities while degenerative changes center on problems involved with bone remodeling including decreased mineral density.

Since only adult tibiae are used in this study, age assessment of subadult bones was unnecessary. However, Harris lines that occur in various locations on the adult shaft are of more value to the researcher if ages can be assigned to each line. The technique of assessing age at the time a specific line forms has most recently been improved upon by Hunt and Hatch (1981). Their techniques and applications to the study will be thoroughly discussed in the next chapter.

Degenerative age effects of Harris lines simply involve the gradual obliteration of dense transverse lines in bone due to progressive endosteal resorption and sub-periosteal apposition. Garn and Schwager (1967) demonstrate a 50% reduction in the frequency of Harris lines in an older sample (age 51 to 86) as compared to a younger sample (age 25 to 50). These authors attribute this reduction to degenerative bone remodeling.

Garn and Schwager's (1967) study has important implications for this study since only adult tibiae from Crow Creek are used and the only age information on these bones is that they are adult. Deletion of old adults or those showing advanced remodeling is not possible.

It is possible, however, to roughly estimate the percent of individuals from this sample that fall into Garn and Schwager's (1967) arbitrary "old" and "young" age categories. Using data from Willey's (1982:37-61) demographic analysis, it can be determined that 22.1% of all adult or near adult individuals from Crow Creek are classified as being 50 to 59 years of age. While this is a substantial percent of the total sample, one should not readily assume that half of all lines in 22.1% of the total sample are obliterated. These figures may be exaggerated due to differences in what each researcher defines as a Harris line. My identification of Harris lines includes those lines that have been extensively remodeled yet they are easily recognizable as transverse lines. (A more detailed description of my definition of a Harris line follows this chapter.) Garn and Schwager (1967), however, ignore all lines that traverse less than 50% of the shaft and thus eliminate most lines that undergo excessive remodeling.

Another item to consider is age differences between Garn and Schwager's sample and the Crow Creek sample. While the former sample has individuals dispersed in a range from 51 to 86 years, Crow Creek individuals have been assessed as being only as old as 59 years. Certainly this upper age limit in Crow Creek is dependent upon and limited to the few accurate techniques of skeletal age assessment in old individuals, but it is not unreasonable to suggest that a sample of prehistoric Plains Indians probably had a shorter average life span than a sample of modern individuals from Fels Institute Study collections. Therefore it is likewise reasonable to assume that overall the Crow Creek sample undergoes considerably less remodeling than that documented by Garn and Schwager (1967). Much more critical to this study is the age at which lines are formed. Therefore all available x-rays of healthy complete adult tibiae from Crow Creek are used in this study.

Sex Assessment

Sex assessment of Crow Creek tibiae can be determined statistically since these methods of sexing skeletal elements are quite common and quite accurate (Dwight 1905; Pearson 1917-1919; Pons 1955; Thieme 1957; Hanihara 1958; Giles and Elliot 1963; Giles 1964; Howells 1970; Steele

1976; Black 1978; Kelley 1979; and others). It is surprising, however, that until recently (Shaivitz and Iscon 1982; Miller-Shaivitz and Iscon 1983; Iscon and Miller-Shaivitz 1983; Symes and Jantz 1983), few of these studies have been applied to tibiae. Because the tibia is a compact weight bearing bone that generally preserves well, sexual dimorphic features should be metrically predictable. This section presents methods developed for sex assignment of Crow Creek tibiae and results of applying these methods.

All Crow Creek Site post-cranial elements were measured by Roger Williams early in 1979 soon after removal from the site. A description of his procedures and measurements are duplicated below:

> Measurements taken followed those described by Bass (1971), though in some instances the procedures used differed slightly (see below). All measurements were recorded to the nearest millimeter (in millimeters). The instruments used to measure the bones were an osteo-metric board, sliding caliper, and a graduated steel tape. . . .
>
> Tibias were measured in the following dimensions: maximum morpological length, physiological length, anterior-posterior diameter at nutrient foramen, medio-lateral diameter at nutrient foramen, and one not listed by Bass (1971), circumference at mid-shaft. Bass (1971) gives the procedure for determination of maximum length according to that used by Trotter and Gleser (1952:473). The procedure used on the Crow Creek tibias differed from the above in that the intercondyloid eminence was placed against the fixed wall of the osteo-metric board and the block applied to the medial malleolus which was then moved side to side and up and down to find maximum length. Tibias with all or part of the medial malleolus missing but with complete proximal ends were included with whole tibias (lengths estimated), also those with intact distal ends but damage to one or both condyles (as long as most of one condyle remained) were included (lengths estimated). A few tibias had nutrient foramina located near midshaft or in the distal half of the shaft. These were marked in the usual location for nutrient foramina and measured anterior-posteriorly and medio-laterally at that point (Williams ms).

To test sexing potential of tibia size, a sample of tibiae from the Larson Site was chosen. The Larson skeletal sample, a post-contact variant of the Coalescent Tradition, is an excellent sample for this type of study since Larson is similar in morphologic affinities and geographic location to Crow Creek. Although individual sex for Larson skeletons is not known, a morphological examination of the innominates produces a very accurate sex assessment.

Four visual criteria on the innominate bone were used to determine sex of the Larson site individuals. These include the 1) ventral arc, 2) sub-pubic concavity, 3) medial aspect of the ischio-pubic ramus, and the 4) sciatic notch. The first three criteria are explained in Phenice (1969) while a description of the last criterion can be found in Bass (1971:159). Each skeleton sexed for this study was required to exhibit at least three of four criteria. All tibiae are from various aged adults with fused proximal and distal epiphyses. Left tibiae were preferred for this study although the right was used if it offered more accurate measurements. In all there were 53 left and 25 right tibiae used in this study.

Only bones allowing the complete set of five measurements were used. Measurements used by Williams (ms) on the Crow Creek material are in Bass (1971) and are originally described in Martin and Saller (1957:572-576). Measurements were recorded to the nearest millimeter (mm.) with no estimations except in cases where the researcher felt that an accurate estimate could be made. All bones were examined for pathologies which might affect any measurement. Quite commonly periosteal reactions occur on the shaft of the tibia near the area of midshaft measurements. If any reactions were assessed as being severe enough to substantially alter any measurement, the bone was rejected.

The five measurements, their descriptions and instruments used to take each measurement are listed in Table 1. All measurements in the Larson series were taken by this author and all instruments were kindly lent by the Department of Anthropology, University of Tennessee. With measurements completed on 40 male and 38 female individuals, all data were analyzed using the DISCRIMINANT subprogram of Statistical Package for the Social Sciences (SPSS) (Nie et al. 1975). Discriminant function analysis was conducted on two groups (males and females), and all five variables (measurements).

Mahlanobis' D^2 is calculated from group centroids and significance for variables was determined by F ratios. Discriminating efficiency was calculated by using distance scores (D/2).

SPSS provides Wilks' Lambda for each variable or variables examined. The goal of discriminant analysis is to maximize distance among groups means. Wilks' Lambda is a ratio of within to total variation (male and female) differences. Therefore a low Wilk's Lambda indicates the largest separation between males and females with the lowest score.

By examining male and female means with respective standard deviations (Table 2), it is immediately evident that there is fairly good separation for all variables suggesting there may be substantial sexual dimorphism displayed in the tibia with these particular measurements appearing sensitive to size differences. Group separation

Table 1. Tibia Measurements and Descriptions.

Variable	Description	Instrument Used
1. Greatest Length*	Greatest possible length--whole bone	Osteometric Board
2. Physiological Length	Lateral condyle to distal articular area, not on intercondyloid eminence or medial alleolus	Osteometric Board
3. Anterior-Posterior Diameter at Nutrient Foramen		Sliding Caliper
4. Transverse at Nutrient Foramen		Sliding Caliper
5. Circumference at Midshaft	Tape was not conformed to morphological concavities	Metal Tape

*All measurements except the author's circumference measurements were taken from R. Martin and K. Saller (1957) Lehrbuch Der Anthropologie. Pp. 572-576, Gustav Fischer Verlag, Stuttgart.

Table 2. Descriptive Statistics for Larson Site Tibiae.

Variable	Male			Female		
	N	Mean (mm)	S.D. (mm)	N	Mean (mm)	S.D. (mm)
1. Greatest Length	40	379.1500	18.7214	38	354.2368	17.6749
2. Physiological Length	40	369.3500	18.7733	38	343.6579	17.3365
3. Anterior-Posterior Diameter at Nutrient Foramen	40	37.7000	2.2441	38	31.5526	1.9549
4. Transverse at Nutrient Foramen	40	24.2500	2.2043	38	21.3158	1.9327
5. Circumference at Midshaft	40	89.2750	4.3382	38	75.2632	4.1309

is analyzed by single variables and combinations of variables in the discriminant analysis summary (Table 3).

While all variables are significant at the .005 level, measurements demonstrating the greatest group separation are circumference at midshaft and anterior-posterior diameter at the nutrient foramen. The other measurements, physiological length, transverse at the nutrient foramen, and greatest length, show substantially less group separation. Interestingly enough, circumference at midshaft and anterior-posterior at nutrient foramen measurements individually produce a discriminating efficiency of 95.08% and 92.76%, respectively. By combining these two variables into a multivariate discriminate function, the discriminating efficiency improves only slightly with an efficiency of 95.31%. Thus the discriminant function calculated for combined variables produces excellent results, but when compared to single variable efficiency, gain is minimal.

By calculating a sectioning point for each variable (male mean + female mean/2), tibiae of unknown sex can be classified by comparing a measurement with the corresponding sectioning point. If the measurement falls below the sectioning point it is classified as female, above classifies as male. Individual measurements and their sectioning points are listed in Table 4. Multivariate analyses are dropped because they add so little to the discrimination.

Applying this sexing technique to the Crow Creek tibiae sample is quite simple. A tibia is sexed according to how the circumference at midshaft measurement compares to the Larson sample discriminant function sectioning point for the same measurement. If for some reason this

Table 3. Discriminant Analysis for Each Variable and Combination of Variables.

Variable(s)	Mahalanobis' D^2	Wilks' Lambda	Discriminating Efficiency	
			D/2	%
1. Greatest Length	1.8709*	0.6759	0.6839	75.30
2. Physiological Length	2.0175	0.6591	0.7102	76.12
3. Anterior-Posterior Diameter at Nutrient Foramen	8.5031	0.3145	1.4580	92.76
4. Transverse at Nutrient Foramen	1.9966	0.6614	0.7065	76.00
5. Circumference at Midshaft	10.9283	0.2630	1.6529	95.08
6. Anterior-Posterior Diameter at Nutrient Foramen with Circumference at Midshaft	11.2393*	0.2576	1.6763	95.31

* All measurements are significant at the .005 level.

Table 4. Highly Efficient Single Variable Sectioning Points.

Variable	Circumference at Midshaft	Anterior-Posterior Diameter at Nutrient Foramen
Female Mean	75.2632	31.5526
Sectioning Point	82.2691	34.6263
Male Mean	89.2750	37.7000
% Efficiency	95.08	92.68

measurement is nonexistent or is of questionable accuracy due to pathological swelling or other influencing conditions, the anterior-posterior diameter measurement and sectioning point was used. The latter measurement was used to sex only eight individual tibiae from the Crow Creek sample.

Skeletal Sample

It is now possible to describe the actual materials used for this study. In all, this study consists of 56 left and 66 right side elements totaling 122 tibiae. By applying discriminant function sexing techniques, 64 (52.5%) are assessed as male and 58 (47.5%) as female. Willey (1982:49) established a similar ratio when sexing the same sample by pubic morphology, with males representing 54.4% and females 45.6% of the sample. To test this discriminant function sexing distribution against that established by Willey (1982:142) using pubic morphology, a chi-square test is calculated. Results show no significant difference between the distributions ($X^2=0.356$, $p \quad 0.500$). Thus tibiae sex estimations produce similar results to pubic morphology assessment of Crow Creek individuals and these overall figures represent a relatively well balanced sample. This balance is less evident, however, when sex and side are broken into separate categories. A majority of the tibiae lie in the male right and female left categories. Combined, these two groups consists of 67% of the total sample (Table 5).

Table 5. Crow Creek Tibiae Sample Size.

Sex	Left	(%)	Right	(%)	Total	(%)
Male	19	(15.6)	45	(36.9)	64	(52.5)
Female	37	(30.3)	21	(17.2)	58	(47.5)
	56	(45.9)	66	(54.1)	122	(100.0)

CHAPTER V

METHODS

Certainly one of the most frustrating problems encountered by researchers attempting to score Harris lines is replicability. Even though few techniques for defining or scoring Harris lines are adequately described in the literature, there is little standardization among researchers. While many studies define Harris lines making "no distinction as to thickness or completeness" (Dreizen et al. 1964:295), others require that lines must extend 50% or more (Garn and Schwager 1967) or 100% of the total diaphysis (Dreizen et al. 1956). McHenry (1968; McHenry and Schulz 1976) separates oblique from transverse lines in long bones, omitting the former because they form "bony spicules or rods extending between two points in the wall of the cavity" instead of forming horizontal "disks." Garn, Silverman, et al. (1968) point out that when these spicules lie transverse to the angle of x-ray, they too appear as bony plates or disks. Heavy, thick-lined subjects have been separated from light, fine-lined subjects (Gindhart 1969) while lines that form in prenatal bone have been frequently ignored (Wells 1967; Allison et al. 1974).

Since tibiae show the highest frequency of Harris lines and seldom form oblique or chevron lines (Garn, Silverman, et al. 1968), this bone seemed suitable for this type of study. All x-rays of the midshaft and distal portions of Crow Creek tibiae were taken between January to May, 1979. All x-rays were generously lent to this researcher by the Archaeology Laboratory at the University of South Dakota under the direction of Dr. Larry J. Zimmerman. Dr. John B. Gregg was instrumental in stimulating all research on Crow Creek x-rays and coordinated all data exchanges. All films were exposed on a Picker, single phase x-ray machine. A Kodak screen cassette was used with Kodak X-Oma RP film (XRP-1), with size 24 x 30 centimeter (cm.) sheets. The tube distance was 40 inches, with KV Range of 50 to 60 and 10 M.A.S. All Kodak film was supplied courtesy of Eastman Kodak Company, Mr. John C. Fink, assistant Vice President, radiography markets division, and Mr. Dale Strimple, regional representative for Kodak company.

Harris Line Identification

Although the term Harris line can apply to numerous features, only those lines, existing partially or completely transverse to the shaft or parallel to former growth plates are counted. While Figure 1 represents a line identified as a Harris line, Figure 2 and 3 represent lines that are randomly oblique to the shaft or are representative of a chevron pattern and are therefore ignored. Line length is highly variable and is commonly considered as a percentage of the total width of the shaft. However, since similar sized adult bones are used exclusively, it is necessary to set only a minimum length that a line must achieve before it is identified as a Harris line. This minimum length is five millimeters (mm.). A line less than this standard length is not counted. The only exception to this rule occurs in cases of extreme resorption where the line is broken into numerous mini-lines combining to form a smoothed image of a complete line (Figure 4). No lines of epiphyseal fusion were counted in this study.

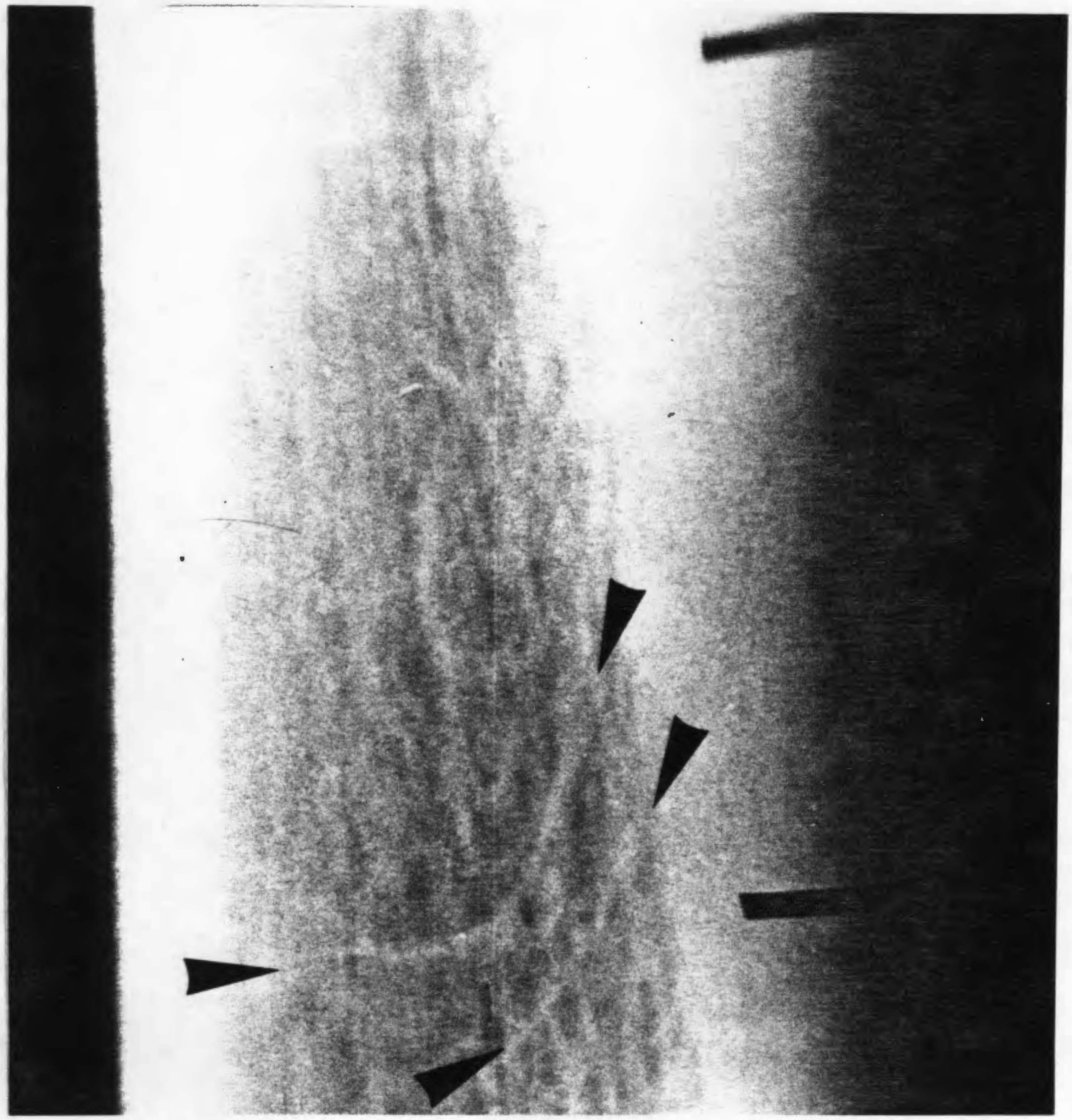

Figure 1. Harris line partially transverse to shaft.

Scale: 4 cm. = Approximately 1 cm.

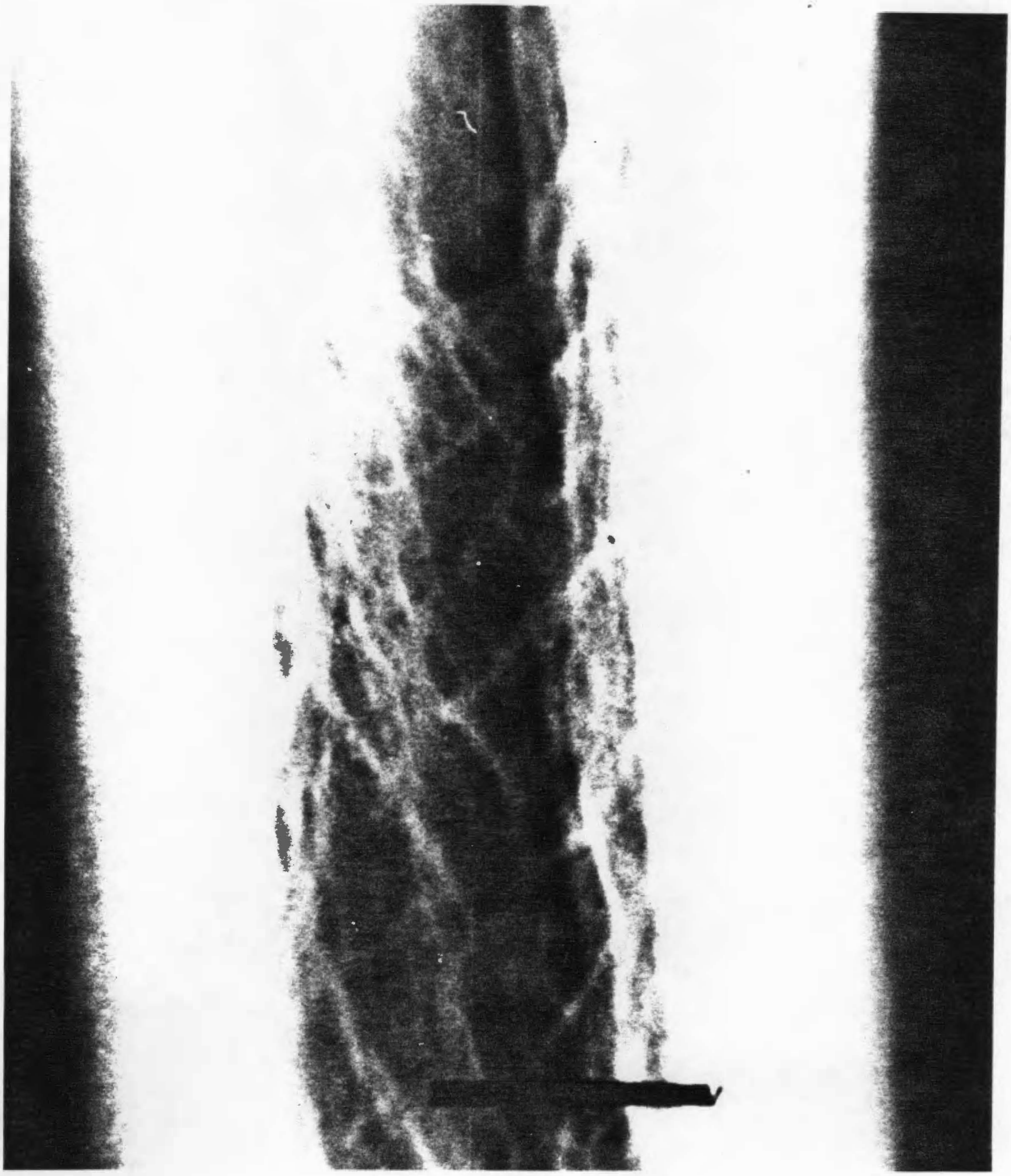

Figure 2. Lines randomly oblique to shaft.

Scale: 4 cm. = Approximately 1 cm.

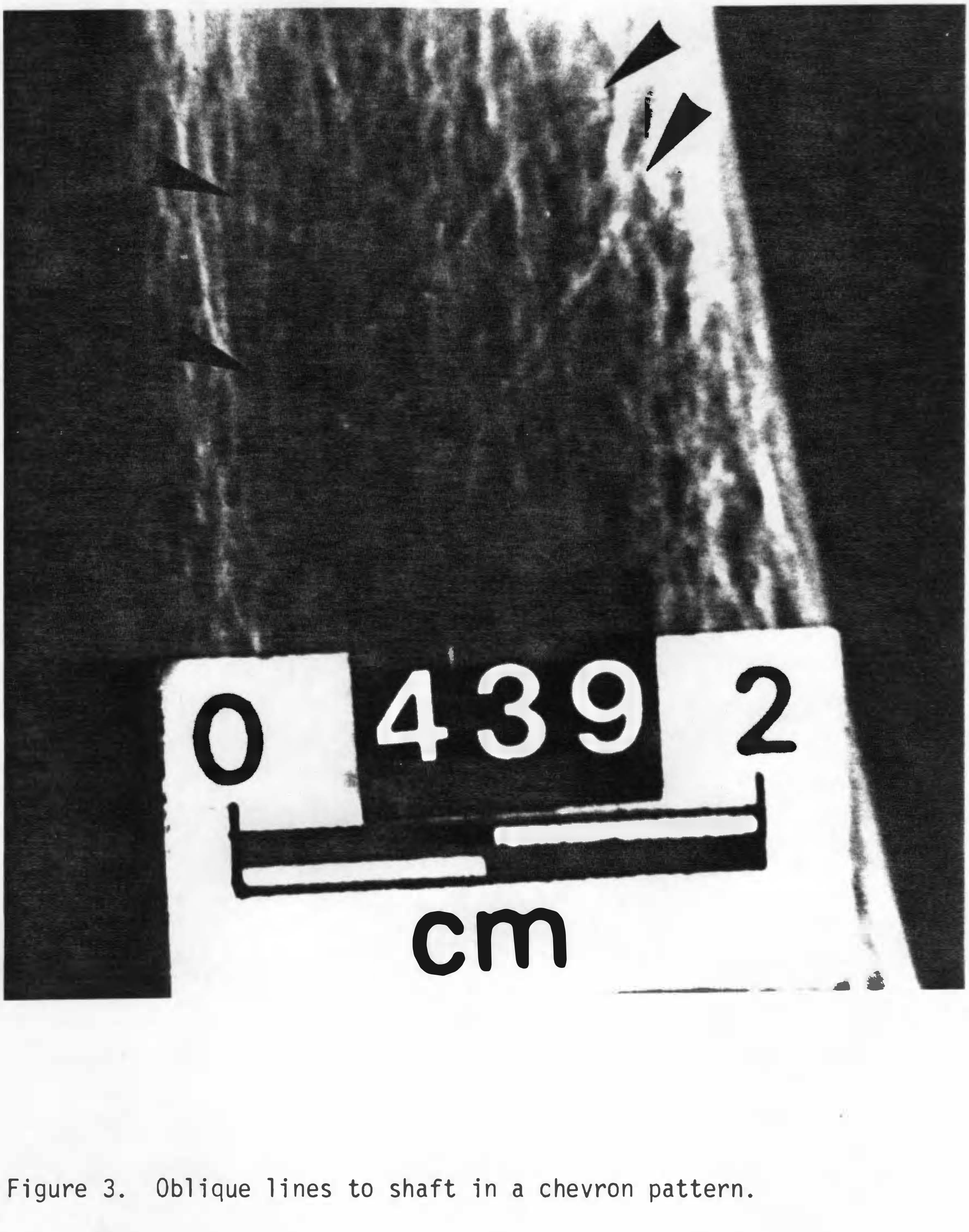

Figure 3. Oblique lines to shaft in a chevron pattern.

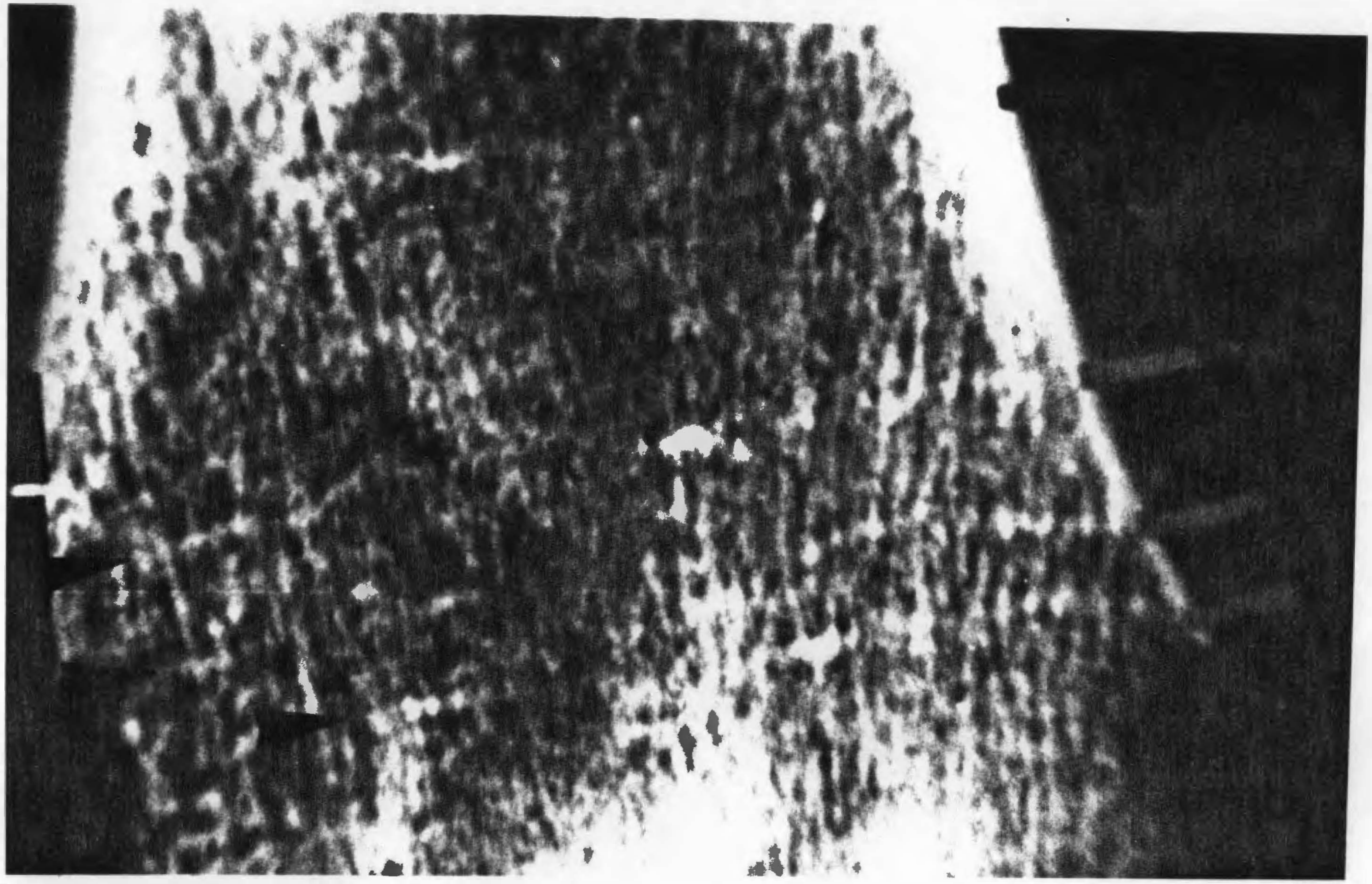

Figure 4. Harris lines exhibiting extreme resorption.

Scale: 4cm. = Approximately 1 cm.

Age Assessment

Harris line age assessment has been attempted in the past. Wells (1967) assessed Harris line ages using a three-fifths proximal and two-fifths distal growth ratio of the tibia. With this technique a constant birth length is subtracted from total diaphyseal bone length. The remaining length is divided into equal increments representing yearly growth. The birth length constant, in this case, is 90 mm. Wells recognized various problems with this type of age assessment:

> This [birth length constant] is uncertain and no doubt even to look for a constant of this kind is an over-simplification. Owing to variations in the rate of proximal or distal growth at different ages the proportion of growth from each is almost certainly a fluctuating one throughout childhood (Wells 1967:403).

However, Wells (1967) justifies his technique since all samples used in his analysis are subjected to the same biases of the technique. This method has also been used by Allison et al. (1974) and McHenry and Schultz (1976).

The technique of age assessment used for this study was introduced by Hunt and Hatch (1981). Hunt and Hatch attempted to reduce these errors and more closely approximate true age at the time of Harris line formation. They divided a double logistic growth curve specific to each sex and population. By calculating total diaphyseal bone length at the time of a specific line formation, comparisons to their growth curve produces an estimated age at line formation. The double logistic curve devised by Hunt and Hatch applies to ages one through eighteen. Neonatal values are produced by multiplying the one year age value by a constant. To calculate total bone length at the time of line formation the bone origin must first be located. This primary center of diaphyseal ossification in the tibia can be estimated in an adult bone using the predicted growth ratio of 57% on the proximal end while 43% occurs on the distal end (Hunt and Hatch 1981).

To demonstrate the Hunt and Hatch (1981) method of Harris line age assessment, a brief step-by-step description of their methods will be listed below. Most computations are conducted using SAS (SAS Institute 1979).

The first step in this analysis is to examine all radiographs and identify Harris lines in distal tibiae. All Harris line assessments were made and double checked by the author. Lines were marked with a thin adhesive tape. Diaphyseal length for each tibia used in this analysis is determined by subtracting 21 mm. from each end or 42 mm. from the greatest tibia length measurement. Twenty-one mm. is the average proximal or distal epiphysis length for an individual 12 years of age. Although Hunt and Hatch (1981) acknowledge that epiphyses still grow after age 12, they suggest that this error is trivial. Crow Creek tibia length measurements are from Williams (ms). The bone origin is calculated as being 43% from the distal diaphyseal tibia. This calculated distance is measured on the x-ray from the most distal point on the x-ray of the bone. In this study the origin was marked with thin colored tape. The greatest distance between the origin and each line was measured to the nearest millimeter. Total length of the bone at the time of line formation is calculated by dividing each line distance by 43%. Since lines form at the growth plate, the distance from this point to a Harris line is only the distal portion of the bone. Therefore, the proximal portion is calculated then added to the distal to find the total diaphyseal length of the bone at the point of line formation.

Measurements taken on any x-ray and those taken on actual bone cannot be expected to yield identical results. Due to the x-ray technique used, parallax distortion can account for a great deal of error, making objects on x-ray larger than actual dimensions. Since this analysis must depend on measurements taken on actual bone then compared to measurements taken of the same bone on film, distortion due to parallax could certainly be an influencing factor. However, it is this researcher's opinion that distortion is not great for this type of analysis.

Obviously, the greater the distance the origin of emitted x-rays lies and the smaller the dimensions of the object to be x-rayed reduces parallax. With the x-ray machine tube 102 cm. from six 24 x 30 cm. film, distortion is minimal. As well, only distal ends of tibiae are placed on the film. Since distal tibiae are small and do not rise high above the film, distortion is again kept to a minimum.

Tibiae must be calibrated in size to the original Denver Whites sample used by Hunt and Hatch. This corrected length for males and females is calculated simply by dividing each male diaphyseal length by 392.0 and female length by 350.0. These constants represent the average diaphyseal length of tibiae for Denver males and females respectively.

Once the tibiae are sexed and corrected lengths are established, each bone can be separated into yearly growth segments using Hunt and Hatch's (1981:462-463) formulae. With bone growth in length computed for each growing year, the researcher need only align each length of bone at the time of line formation with the closest corresponding yearly growth segment constant. Thus, the yearly age associated with the constant that most similarly matches bone length at line formation is the age at line formation.

Newborn Length

Up to this point, the Hunt and Hatch method of age assessment has been used without alteration. Problems arise however, when tibia bone length at birth is considered. The Hunt and Hatch newborn tibiae length for Denver Whites is 59 millimeters. When this newborn constant was applied to Crow Creek tibia, which were substantially shorter than Denver White tibiae, the population-specific correction factor produced newborn tibia lengths of approximately 51 millimeters. From personal observations of newborn Arikara children it seemed clear that this figure was too short for newborn length, especially when compared to prior studies which eliminate lines occuring at 90 millimeters or less (Wells 1967; Allison et al. 1974; McHenry and Schultz 1976). A range of 51 to 90 millimeters for newborn tibiae length could be proposed but a range of that magnitude does not seem appropriate for this study.

Many past studies have dealt with newborn length. Fazekas and Kosa (1978:232-277) have reviewed early studies dealing with neonatal and prenatal bone measurements. One of the oldest studies cited for this type of information is Kanzler's 1854 description of data gathered by Nicolai and Beclard. These researchers establish newborn tibia length at 62.2 and 60.0 respectively (see Fazekas and Kosa 1978:232). Fazekas and Kosa (1978:263) themselves give full term tibiae length as being 65.1 for males and females combined while McCammon (1970:181) reports a newborn to 2 months tibiae length at 70.6 mm. Stewart (1979:132-135) takes a slightly different approach and established a frequency distribution of tibiae lengths on a protohistoric Arikara Indian site (39WW1). This distribution produced a concentration of bones within a range of 63.0 to 74.5. The mean length of these two figures is 68.8. Since it can be assumed that death most frequently occurs at childbirth, Stewart stated that these figures strongly suggest accurate Arikara tibiae length at birth.

Summarizing the literature of tibia newborn length, it would seem that this bone is most likely in a range of 60 to 70 mm. at birth with most recent research suggesting a length from 65 to 70 mm. This again suggests that the Hunt and Hatch (1981) standard for newborn tibiae is much too small and needs to be revised. Since Crow Creek material is most closely related to Arikara Indian material, it is more appropriate to devise a standard based upon Arikara rather than other skeletal samples.

Owsley (ms), in an analysis of Arikara Indian development and mortality, has measured numerous skeletal elements using seven sites extending from prehistoric to historic times. Utilizing Stewart's (1979:132-135) technique and Owsley's data, a frequency distribution was established for all tibia 59 to 79 mm. in length, all sites combined. The results (Table 6) demonstrate a concentration of tibiae at the 68 to 69 mm. length. Since this study closely coinsides with the findings of Stewart, the value of 68.5 is deemed a more accurate constant newborn tibia length than the figure provided by Hunt and Hatch.

Table 6. Frequency Distribution of Subadult Arikara Tibiae 59 to 79 Millimeters.

Total Length	Number
59	4
60	4
61	5
62	6
63	16
64	16
65	17
66	23
67	29
68	42
69	46
70	33
71	25
72	23
73	7
74	6
75	6
76	5
77	4
78	4
79	4

With birth length of tibiae established at 68.5, the Hunt and Hatch method must be revised to use this value. Since it is likely that most Crow Creek newborns have a tibia length similar to 68.5 mm., it was decided that for this study all tibiae should approach this value, irregardless of total adult length. To accomplish this, sex-specific mean adult tibiae lengths are calculated for Crow Creek as a whole rather than for each bone. Next, a correction factor is produced to make Hunt and Hatch age values correspond to the shorter adult Crow Creek sample. With yearly age values population-specific to Crow Creek, a constant for each sex need only be multiplied by corresponding one year values to produce birth lengths of 68.5 mm. The constants that produce birth lengths specific to Crow Creek are 0.7009 for males and 0.6788 and females respectively.

Prenatal Lines

Some lines may occur before this calculated newborn length is reached. Very little research has been done on prenatal lines. This indicates either paucity of line formation before birth or a recognition problem with prenatal lines. Wells suggests the latter:

> It is worth noting here that a transverse line may be seen as a rare anomaly in a part of the bone which corresponds to its prenatal length. The interpretation of a line in this position is uncertain. It is doubtful whether they are true Harris's lines and they are best ignored (Wells 1967:404).

Allison et al. (1974:410) simply states that "lines that fell in the prenatal area were not counted in the study as their interpretation was considered unsatisfactory."

Certainly, it is difficult to deal with prenatal growth, especially in terms of age prediction. However, these form potentially valuable record of information that should not be ignored. Although the occurrence of these lines is rare, they will receive equal treatment in this research. Obviously prenatal lines cannot be categorized into years before birth, but using fractions of years before birth would be consistent with the yearly age assessment of lines after birth. For example, prenatal growth is often considered in terms of lunar months with full term development occurring in the tenth lunar month. Dividing these lunar months into fractions of years, seven months of fetal development represents approximately one-fourth (.23) of a year before birth. Three months represent just over one-half (0.54) a year before birth. To study prenatal lines, approximations of tibia bone length at these periods of development are needed as standards. Fazekas and Kosa (1978:232-277) carefully outline tibia dimensions throughout ten lunar months of prenatal development and their standards are used here. Comparing prenatal lengths to birth lengths, a constant can be developed for one-fourth and one-half years before birth. If bone length at prenatal line formation is compared with bone length at birth, a value is produced that is comparable to the prenatal constants. Thus prenatal lines are calibrated the nearest fraction of a year before birth.

This is a new technique whose reliability has not been assessed. No standard prenatal growth curve has been established nor have Crow Creek line measurements been calibrated in any way to the Fazekas and Kosa fetal sample. However, worldwide studies of human growth strongly suggest the basic reliability of the method. It is logical to assume that growth is predictable in humans whether it is before or after birth, and prenatal growth is likely more predictable and less susceptible to environmental stress than postnatal growth. Due to this predictability, the Fazekas and Kosa mean lengths are probably similar to those of Crow Creek. The advantage of the technique is that it provides a way to identify all lines. Using an untested technique in this case appears more defensible than simply eliminating all prenatal lines.

CHAPTER VI

RESULTS

Harris lines are evident in Crow Creek distal tibiae and they apparently occur with some regularity. While some individual tibiae completely lack any trace of transverse lines (Table 7), close to three-fourths of the bones studied did contain at least one radiopaque line (Table 8). While most individual elements exhibited one line, numerous tibiae contained multiple lines with 10 lines being the highest frequency for any single element. Of the 92 tibiae that exhibit lines, a total of 163 lines were recorded (Table 9). Each line when aged falls into an age range of -0.5 to 18 years. Figures 5 through 8 graphically illustrate Harris line frequencies for each sex and side by age at line formation.

Table 7. Number and Frequency of Tibiae Exhibiting No Harris Lines Out of a Possible 122 Elements.

	Side					
Sex	Left	(%)	Right	(%)	Total	
Male	6	(4.9)	9	(7.4)	15	(12.3)
Female	9	(7.4)	6	(4.9)	15	(12.3)
	15	(12.3)	15	(12.3)	30	(24.6)

Table 8. Number and Frequency of Tibiae Exhibiting Harris Lines Out of a Possible 122 Elements.

	Side					
Sex	Left	(%)	Right	(%)	Total	(%)
Male	13	(10.7)	36	(29.5)	49	(40.2)
Female	28	(23.0)	15	(12.3)	43	(35.2)
	41	(33.6)	51	(41.8)	92	(75.4)

Table 9. Number and Frequency of Harris Lines in Distal Tibiae.

	Side					
Sex	Left	(%)	Right	(%)	Total	(%)
Male	18	(11.0)	71	(43.6)	89	(54.6)
Female	47	(28.8)	27	(16.6)	74	(45.4)
	65	(39.9)	98	(60.1)	163	

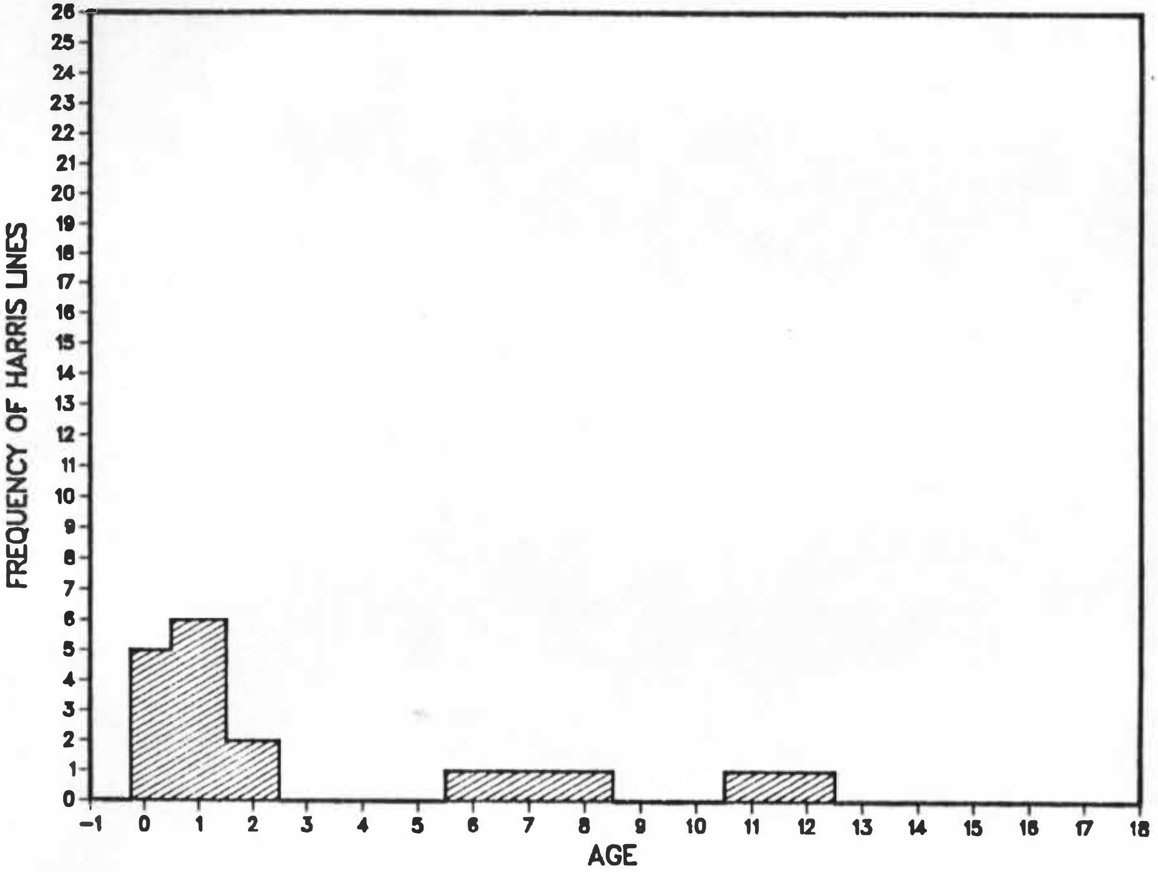

Figure 5. Harris lines of left male tibiae.

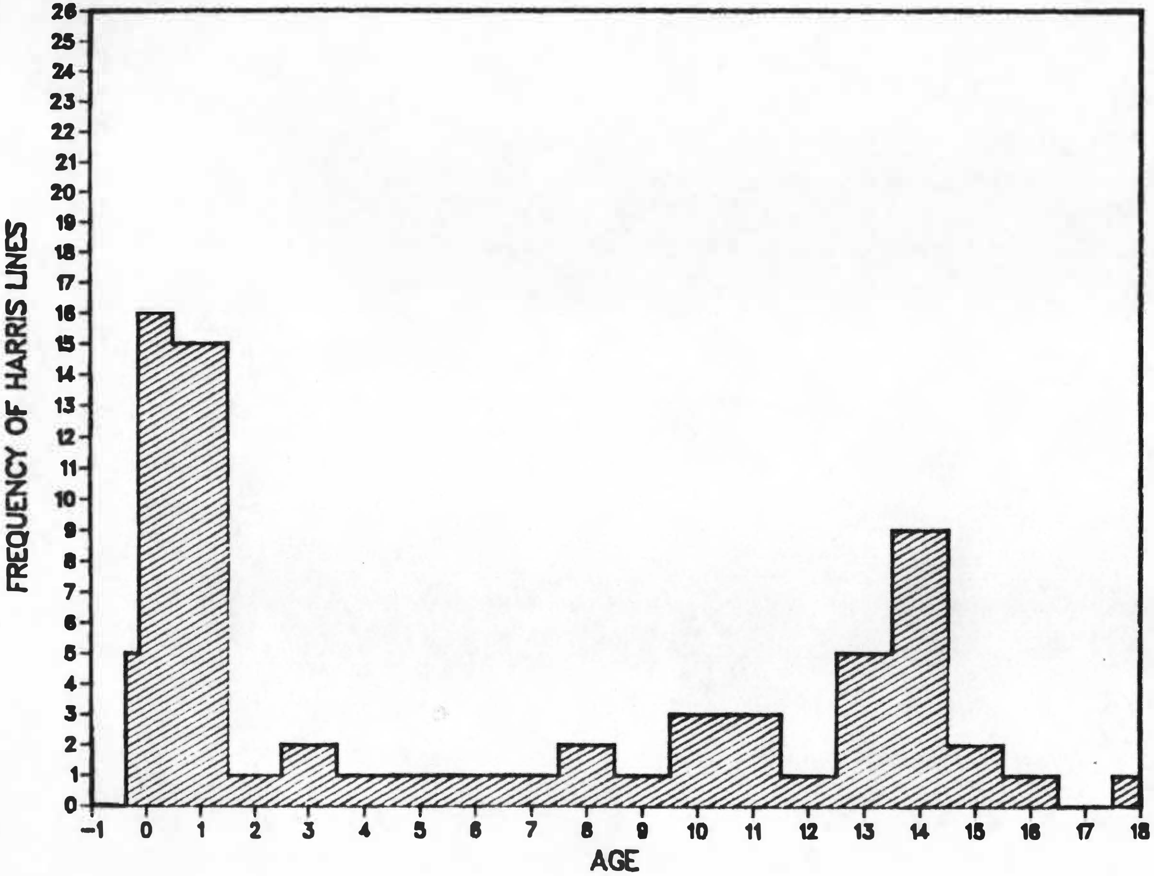

Figure 6. Harris lines of right male tibiae.

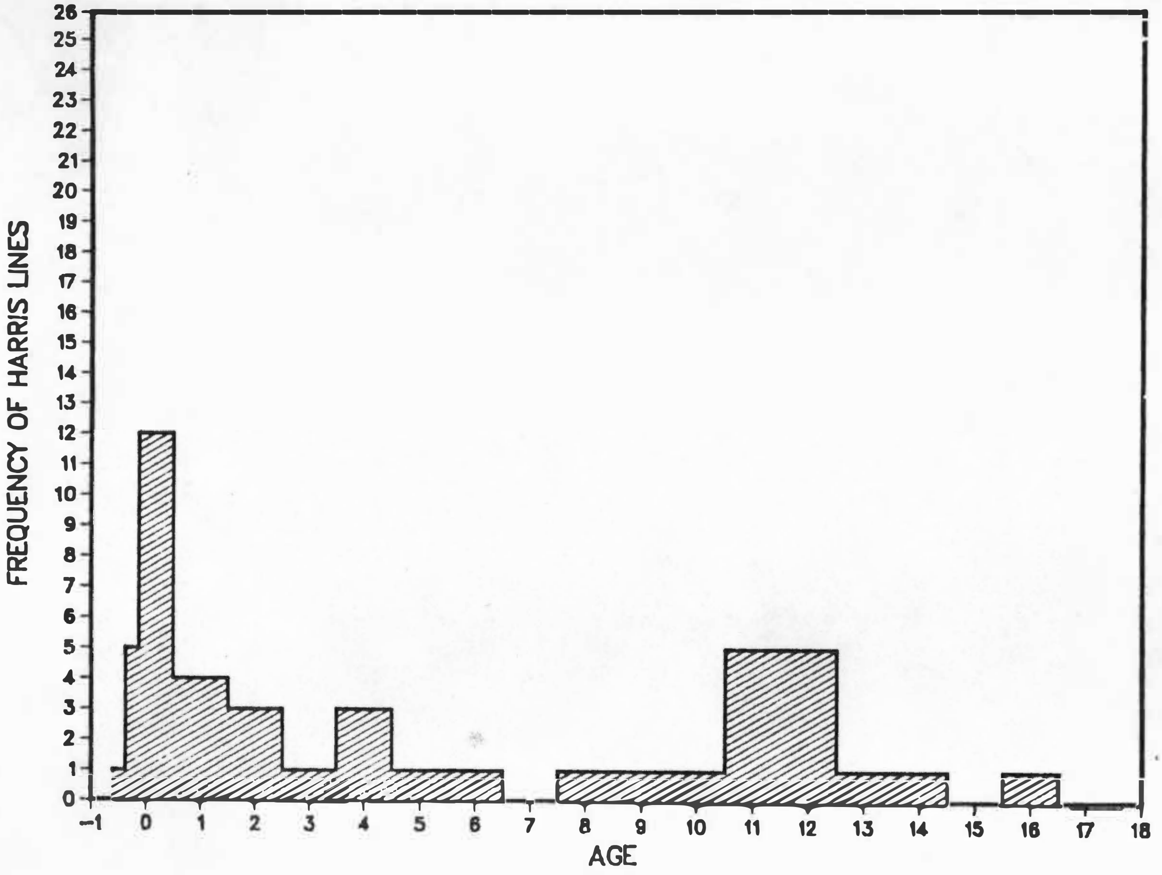

Figure 7. Harris lines of left female tibiae.

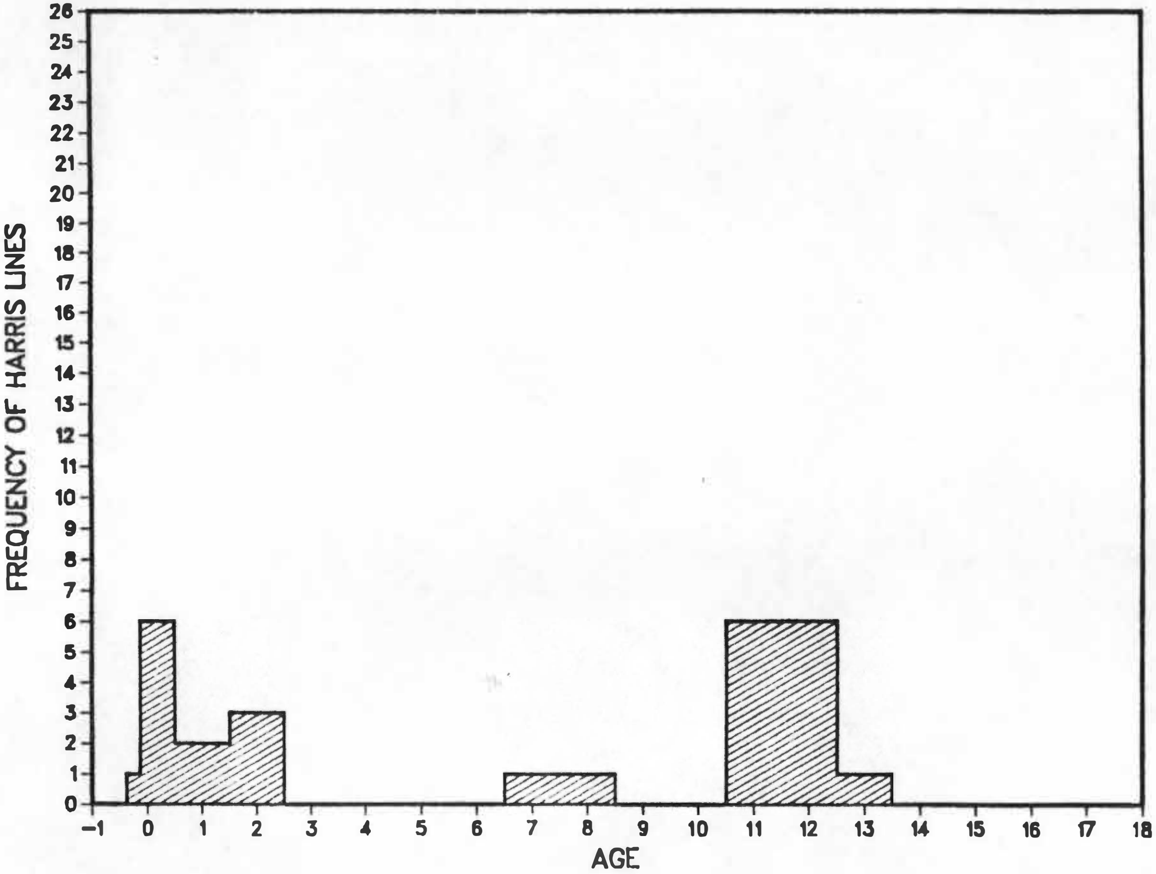

Figure 8. Harris lines of right female tibiae.

With this information available, it is now possible to address the hypotheses presented in Chapter III. Hypothesis I assumes that Harris lines are non-specific indicators of stress and are of value to anthropological problem solving on the individual and population level. While this hypothesis does provide an essential base for subsequent hypotheses to build upon, testing is difficult since initial results offer little to prove or disprove this hypothesis. Hypothesis I will be discussed more fully in Chapter 7 so information gleaned from the following hypotheses and discussions may be more appropriately utilized.

Hypothesis II states that frequency comparisons of Harris lines in a skeletal sample should produce observable sex differences. As mentioned above, this hypothesis simply assumes there are obvious biological differences between boys and girls and it is likely these differences influence, in some manner, the formation and retention of non-specific indicators of stress, or in this case, Harris lines. However, initial examination of frequencies of individual tibiae with and without Harris lines give no indication of sex bias (Table 7 and 8). The same is true for frequencies of actual lines in bone (Table 8) since lines appear to be equally distributed considering sample sizes.

To test this initial assessment, a statistical test of these distributions can be performed on the average number of Harris lines expected to occur in each tibia by sex. Using the predictive values of line occurrence in Table 10, a Student's t-test produces a value of 0.5819 for left and 0.7913 for right tibiae sex comparisons. Neither test approaches significance at the 0.05 probability level. While tibiae sorted according to sex are comparable, side comparisons have limited application since it is impossible to determine which elements belong to the same individual. However with the use of a t-test, it is possible to compare the largest samples of tibiae for males and females even though these occur on opposite sides. Sex differences tested in this way are not significant at 0.05 (t=1.27).

Table 10. Predictive Values of Harris Line Occurrence in Crow Creek Tibiae.

Sex	Side		Total
	Left	Right	
Male	0.95	1.58	1.39
Female	1.14	1.23	1.28
	1.16	1.48	1.34

Hypothesis III states that since Harris line formation depend upon reduction or arrest of histological bone growth followed by recovery, overall growth velocity changes affect the formation of these bony lines. As mentioned above, this hypothesis suggests a relationship between line formation and growth velocity.

To test this hypothesis, a human growth velocity curve is compared with Harris line frequencies. Once again comparisons of commingled elements must be avoided. Just as problems arise when right and left elements are combined, it is also incorrect to combine elements from different sexes because boys and girls grow differently. However, most of these differences occur in the timing of the prepubertal spurt while growth up to this point or up to about nine years of age, is for most purposes all but identical (Tanner 1978:14). Therefore if Harris line frequencies are charted with a growth velocity curve from birth to 9 years, sexes can be combined to achieve maximum sample size and still test for correlation of line formation and growth velocity. Figures 9 and 10 represent left and right tibiae line totals with a modal human growth velocity curve. Similarities in each curve shape is readily noticeable.

Since this initial test suggests similarities in curve shapes, this test is carried one step farther by looking for similar correlations when controlling for sex. Due to sample size limitations, only right male and left female tibiae will be considered. However, these frequencies can now be compared to sex-specific growth charts extending for the total growth period.

Figure 11 represents right male tibiae line frequencies compared with a male growth velocity curve. There seems to be similarities with peak periods of growth velocity and line frequencies. Male peak periods occur at birth and near 14 years of age. A similar correlation is shown in left female tibiae (Figure 12) with the major peak at birth and a second peak near 12 years of age.

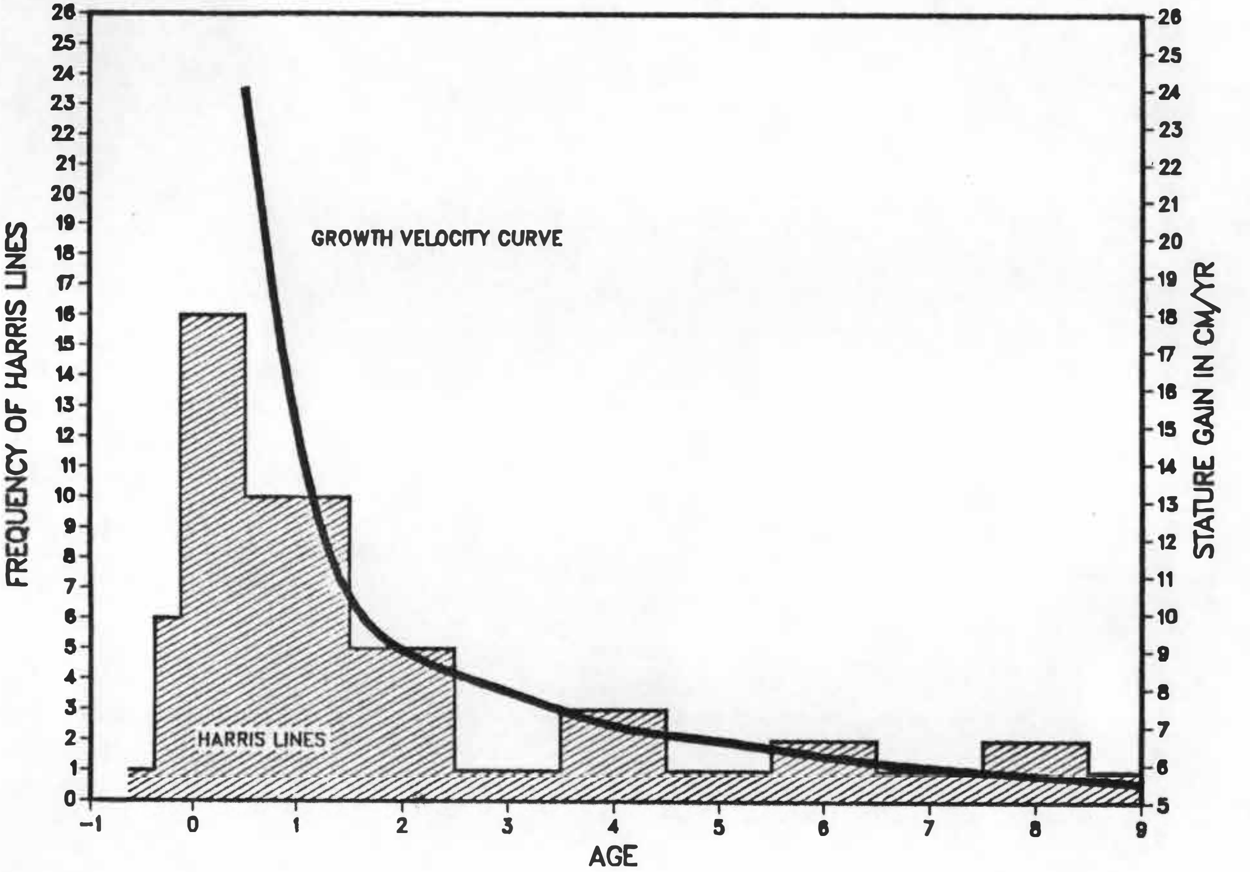

Figure 9. Combined sex Harris lines of left tibiae compared to a human growth velocity curve through age nine.

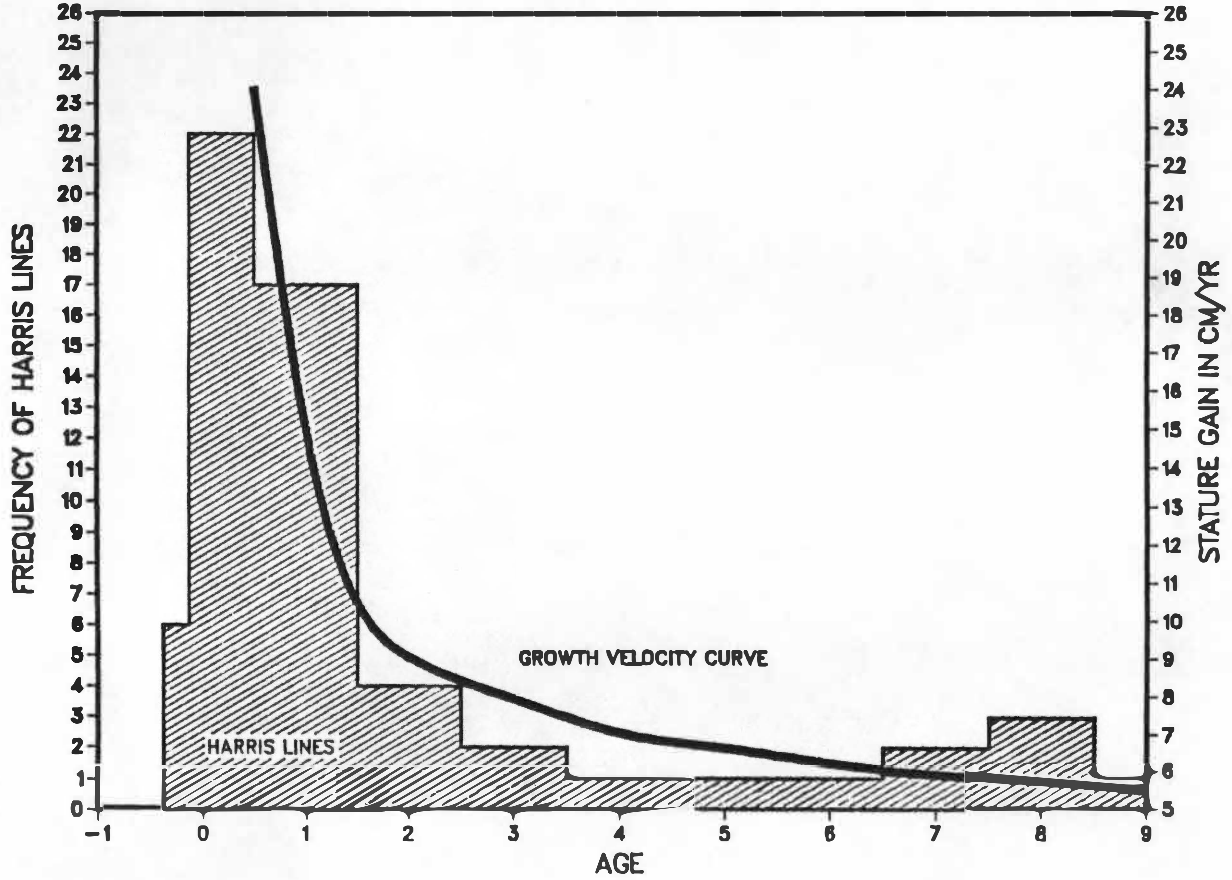

Figure 10. Combined sex Harris lines of right tibiae compared to a human growth velocity curve through age nine.

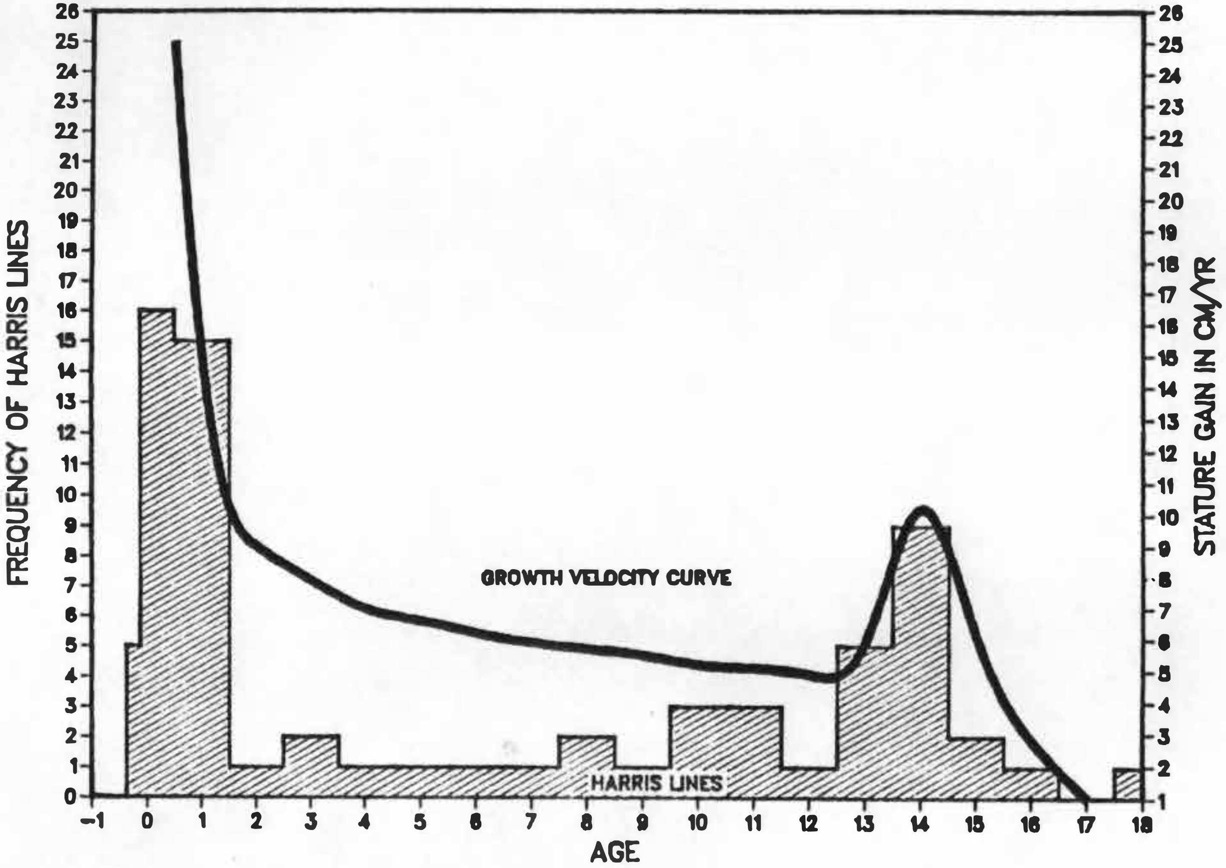

Figure 11. Harris lines of right male tibiae compared to a human male growth velocity curve.

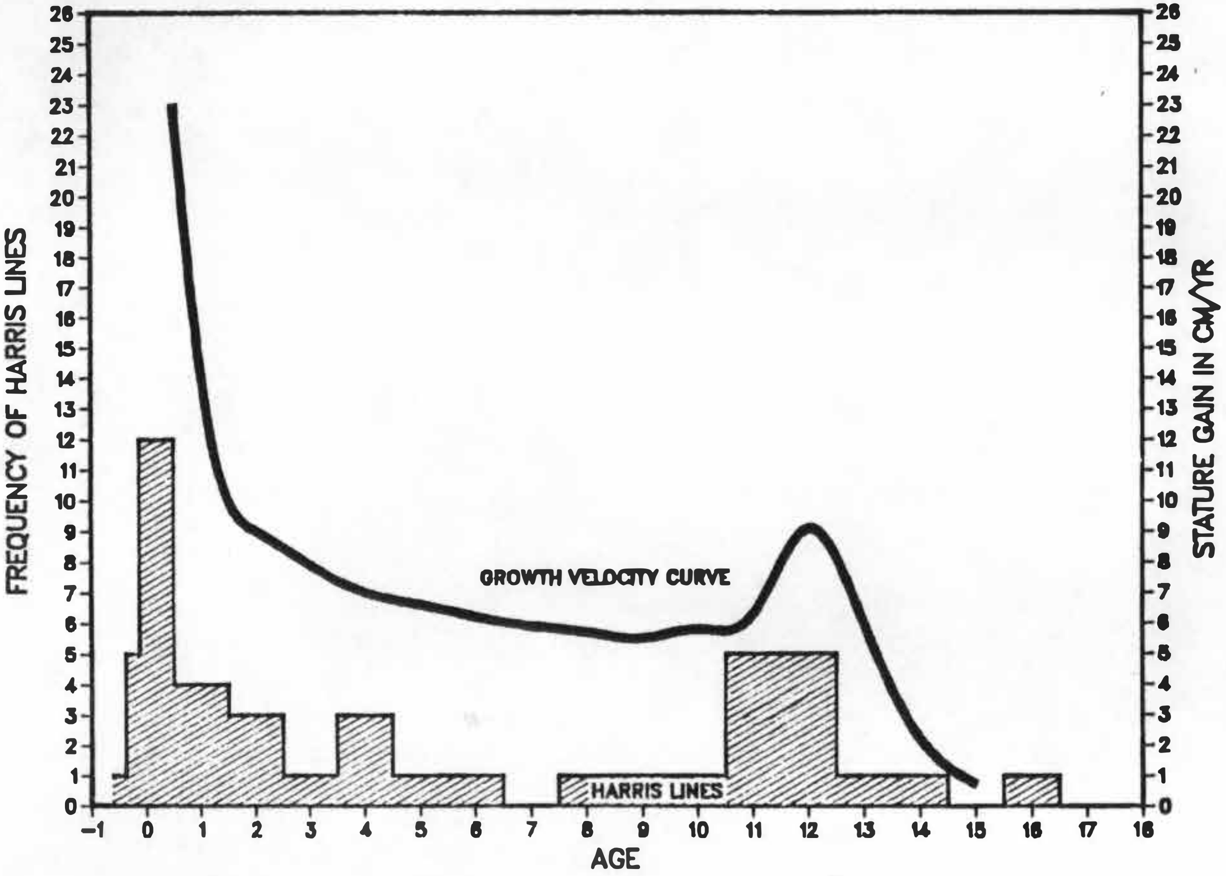

Figure 12. Harris lines of left female tibiae compared to a human female growth velocity curve.

CHAPTER VII

DISCUSSION

Sex Influences on Harris Lines

Documented sex differences in Harris line formation is rare in studies using archaeological samples (eg. Marshall 1968). However sex differences among living samples are well documented. Gindhart (1969) found sex differences in Harris line formation and retention using a longitudinal sample from the Fels Human Development program. By comparing percent of new individuals showing new lines she found:

> Highest frequencies occur from 1.0 to 4.0 years in the boys, with another peak at 5 years; and from 1.0 to 3.5 years in the girls, with a gradual decline in both sexes through the fourteenth year. The highest percentage of appearance of new lines, 34%, occurred in girls at 2.5 years, but in boys the peak was almost double this, 61%, at 2.0 year (Gindhart 1969:19).

Boys in this study also experienced higher frequencies of line formation but lines persisted longer in girls.

Crow Creek tibiae results bear little resemblance to Gindhart's study. Looking at Figures 5 through 8, the highest frequencies of lines for boys appear from -0.25 to one year and again at 13 and 14 years. Girls are similar with peaks from -0.25 to two years and again at 11 and 12 years. Between these peaks there is generally a sharp decline and leveling off. Peaks appear approximately equal in magnitude in males and females.

Lack of similarities between Gindhart's (1969) study and this study are substantial but not difficult to explain. Gindhart is analyzing a modern sample of healthy American children while Crow Creek represents a prehistoric American Indian population. It is difficult to suggest that any indicator of stress would follow similar patterns in these two groups. Gindhart's study also demonstrates short Harris line persistence. No line persisted over 6 years in males and while females had longer lasting lines, few, if any, persisted into adulthood. Crow Creek children probably developed lines that disappeared at a young age, but lines do persist into Crow Creek adults unlike the modern sample.

Therefore, it can be suggested that comparisons of patterns between a longitudinal modern sample and a skeletal prehistoric sample should be avoided. Sex differences observed in Gindhart's (1969) study evidently are not exhibited at Crow Creek and should not necessarily be expected to. While sex may influence Harris line formation and retention, it seems that these influences are subtle enough that skeletal samples display few sex differences.

Even though patterns of line formation are evident in Crow Creek tibiae, few of these patterns can be attributed to sex influences. Hypothesis II expected Harris lines to detect biological sex differences but it is likely that these differences are too subtle for this indicator of stress to detect using this type of sample.

Developmental Age Influences on Harris Lines

Park (1964:833) alludes to developmental age effects on Harris line formation suggesting that since growth is most rapid in the first months of life, lines will be more frequent in this period. Dreizen et al. (1964:305) specifically state that "growth interrupting disturbances which intervene during the most rapid phase of bone lengthening are the most apt to leave bone scars."

Mensforth (1981:40) takes a different stand by suggesting that "major genetically controlled and neuroendocrinologically regulated periods of growth velocity . . . may enhance chondroblastic stability thereby rendering the cartilage growth plate less sensitive to environmental perturbations." Mensforth demonstrates this "periods of stability" hypothesis by charting Harris line frequencies for specific ages in a Woodland Indian tibia sample against a (male) human growth velocity curve. He finds a negative relationship between line frequency and growth velocities (Figure 13). Thus Mensforth agrees that periods of differing growth velocities may influence Harris line formation, but at the same time he argues that the cartilage growth plate is less sensitive to environmental insults during childhood growth spurts and would therefore have fewer lines during those periods of high growth velocity.

As shown in Figures 11 and 12, Crow Creek tibiae line frequencies create curves similar to human growth curves. These contradict Mensforth's (1981) findings (Figure 13). Whereas he proposes enhanced stability against line formation during growth spurts, the Crow Creek results agree with past researchers like Park (1964) and Dreizen et al. (1964) and suggest that the cartilage growth plate is much more susceptible to line formation during periods of high growth velocity. This is typlified by high frequencies of lines formed not only during the neonatal growth spurt, but also during the adolescent growth spurt. For the first time sex differences appear since increasing line formation in both boys and girls corresponds to their respective growth velocity curves.

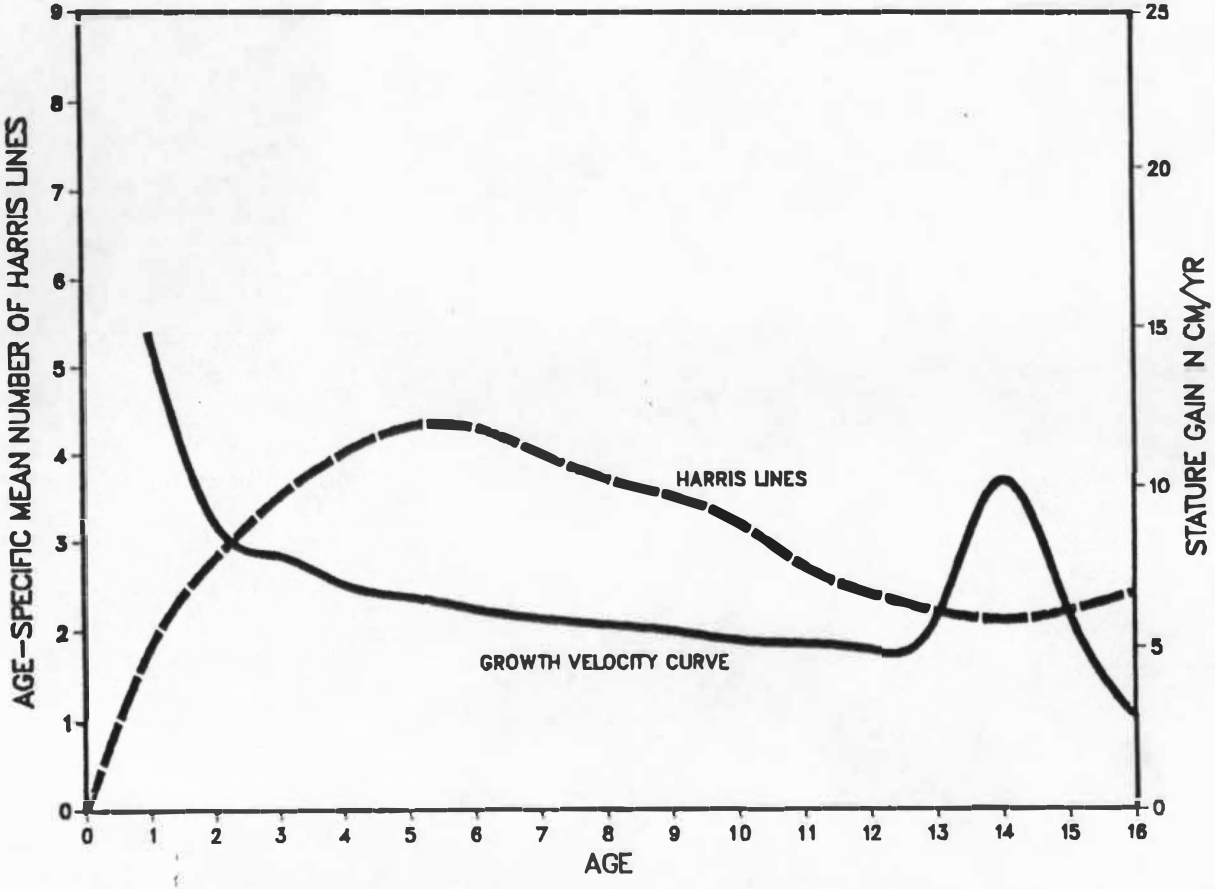

Figure 13. Mean Harris line frequencies for Libben samples with human male growth velocity curve.

Source: Robert P. Mensforth, (1981), Growth velocity and chondroblastic stability as major factors influencing the pathogenesis and epidemiological distribution of growth arrest lines. Paper presented at the Fiftieth Annual meeting of the American Association of Physical Anthropologists, Detroit, MI.

Harris Lines As Indicators Of Stress

Hypothesis I simply states that Harris lines are non-specific indicators of stress and are therefore likely to be of some anthropological value for individual and population studies. While Hypotheses II and III were based on these assumptions, Hypothesis I can be discussed in terms of the findings of these latter hypotheses.

Assuming tibiae sexing and aging of lines were performed accurately for this sample, Harris lines appear to show little distinction between sex while being heavily influenced by growth velocity. There is some evidence that sex separation of line frequencies does occur (the adolescent growth spurt) but this is dependent upon stringent age controls. While the lack of demonstrable sex differences does little to add to the credibility of Harris line analysis, it does not substantially distract from its utility. Assuming Harris line formation is related to growth velocity, the analysis and interpretive value of this indicator of stress is reduced considerably. Certainly the lines analyzed in this study are those that persisted into adulthood and are likely remnants of childhood stresses. However, not only is the type and severity of stress important to line formation and persistence, but also the age at which this stress occurred. Or more precisely, it is important to know at what point in the growth cycle the stress occurred in order to allow stress marker comparison.

Undoubtedly, the dynamics of Harris line analysis and interpretation are complex. While many previous studies have questioned the validity of Harris lines as non-specific indicators of stress, this analysis suggests that line formation is heavily dependent upon individual growth velocity. Thus this analysis assumes that Harris lines evident in adulthood are stress induced; it is the usefullness of these lines to anthropological studies that is being questioned. This analysis demonstrates that Harris line analysis, as it has been approached in previous anthropological studies, has little value as a stress indicator.

CHAPTER VIII

SUMMARY

This study has analyzed Harris lines of the adult distal tibiae of Crow Creek Massacre victims. These lines are separated by bone side, sex and age at the time of formation. Specific age at death for each tibia is lacking.

About three-fourths of the total 122 tibiae exhibit at least one radiopaque line with an average of 1.34 lines occurring per element. When assigning ages to each line, a range from -0.5 to 18 years is produced. The most common ages for these lines to appear in this sample are in early adolescence and near the time of birth. While Harris lines formation in modern longitudinal studies have revealed sex differences, these differences are likely subtle in adults and are not statistically significant in this sample. The only exception to this occurs when tibiae are analyzed with age-specific Harris lines. Here, frequencies appear to peak at slightly different ages in adolescent boys and girls. Growth velocity effects on Harris line formation are tested using sex- and age-specific line frequencies plotted against respective male and female growth velocity curves. The similarities in growth curve shape and male and female frequencies suggest that line formation is accelerated during common growth spurts and slowed during decreased growth velocity years.

Assuming sex and age assessments performed for this study are accurate, the reliability of Harris lines as non-specific indicators of stress is strongly questioned. Certainly Harris lines cannot be considered useless for all anthropological application due to the limits of this study. However, if one assumes that Harris line formation is dependent upon growth velocity, Harris line analysis, as it has been approached in previous anthropological studies, has little value as a stress indicator.

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