

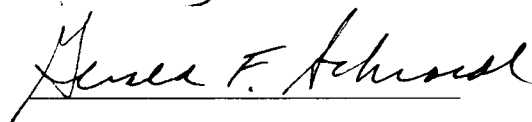
To the Graduate Council:

I am submitting herewith a thesis written by Rebecca St. James Redmond entit.
"Nutritional Stress and Femoral Cortical Thickness among Central and Northern
Indians from the Prehistoric to the Historic Period." I have examined the final co,
this thesis for form and content and recommend that it be accepted in partial fulfill
of the requirements for the degree of Master of Arts, with a major in Anthropology.



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We have read this thesis
and recommend its acceptance:



Accepted for the Council:



Associate Vice Chancellor and
Dean of The Graduate School

**Nutritional Stress and Femoral Cortical
Thickness among Central and
Northern Plains Indians from the Prehistoric to the Historic Period**

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

Rebecca St. James Redmond
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DEDICATION

This thesis is dedicated to my parents, Marie and John Redmond,
to whom I am eternally grateful.

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ABSTRACT

This study investigates the effects of changing nutritional status on femoral cortical bone among Plains Indians affiliated with sites in Nebraska, South Dakota, and North Dakota from the Plains village period to the Reservation period. Previous studies have examined the relationship of nutritional stress and loss of cortical bone for Plains Indians but this study uses a larger sample and expands the number of groups.

Cortical bone thickness measurements, medullary cavity width and total subperiosteal diameter, were taken directly from radiographs of femora. The general linear models analysis of variance statistic was used for evaluation of both the primary and derived variables. Sites included in this research are divided into either Central Plains or Northern Plains sites and then are further subdivided into archaeological variants specific for the geographic area of study.

The Central Plains archaeological variants were expected to show an increase in bone cortex between the Central Plains tradition and the Lower Loup phase due to improving climatic conditions and availability of bison. A decrease was expected between the Lower Loup phase and the Disorganized Coalescent variant, when the Pawnee were experiencing epidemic disease and inter-tribal conflict. For the most part, the expected mean differences were observed but these differences were not statistically significant. The means for medullary cavity width for the Central Plains tradition were especially unexpected.

In general, statistical results for the Northern Plains sites reveal expected patterns of nutritional stress as reflected in the variable means. A rise in cortical thickness is expected and observed between the Extended and Postcontact Coalescent variants. Expectations are also met for the Disorganized Coalescent since a decline in Arikara cortical thickness is evident as they were faced with increasing problems due to Euroamerican contact. One problem of unexpected mean values is found with the Initial Middle Missouri variant. This sample was expected to demonstrate high levels of nutritional stress; however, this is not supported by the results.

One possible explanation for the exhibition of minimal nutritional stress among the Central Plains tradition and Initial Middle Missouri tradition samples is offered. These prehistoric groups may have been maintaining high levels of activity while in search of food. Since the femur is a weight bearing bone, activity levels are more likely to stimulate bone growth in the femur. High levels of activity may have counteracted any loss of bone caused by nutritional stress in these samples.

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I. INTRODUCTION

Skeletal evidence has contributed much to current knowledge concerning the physiological responses of prehistoric and historic American Indians to environmental and cultural stressors. Archaeological and historical information reveal that external constraints such as climate, inter-tribal conflict, and disease were responsible for nutritional stress among Plains Indian tribes.

This research focuses specifically on nutritional stress encountered by archaeological groups living on the Central and Northern Great Plains. While stressors cannot be measured directly from skeletal remains, the skeleton retains markers of stress allowing physical anthropologists to assess the amount and types of stress individuals were encountering (Goodman et al., 1984:16). One physiological response or indicator of nutritional stress is a reduction in cortical bone thickness. Research demonstrates that the higher the estimated level of nutritional stress the lower the expected value of femoral cortical bone thickness. This finding is examined with archaeological samples of American Indians from sites in the Central and Northern Plains dating to the prehistoric through the historic period.

Previous studies have investigated cortical bone thickness as an indicator of nutritional stress (Hummert, 1983; Pfeiffer and King, 1983). Owsley (1985, 1991) has demonstrated the relationship between nutritional stress and loss of femoral cortical bone for Arikara from South Dakota sites affiliated with the Coalescent tradition. This study proposes to investigate a larger data set, it includes the South Dakota Coalescent

tradition sites already reported on by Owsley (1985, 1991), and it expands the sample by adding four Initial Middle Missouri sites, a historic site in North Dakota, and a sample of Crow, all of which are not included in Owsley's (1985, 1991) reports. However, the greatest expansion of the data that is not reported on by Owsley (1985, 1991) is the Central Plains sample. This sample consists of prehistoric and protohistoric Central Plains villagers (Central Plains tradition and Lower Loup phase samples) and the Disorganized Coalescent Pawnee, all from sites in Nebraska. The goal is to provide a broader understanding of the effects of nutritional stress on cortical bone by researching a larger Plains Indian sample.

Research Expectations

Cortical bone loss is an indicator of stress. Physiological disruption is the result of three factors: environmental constraints, which vary by time and space; cultural systems; host resistance, which varies by age and sex; and genetics (Goodman et al., 1984:15). Two sources of nutritional stress that Plains Indians encountered were in the form of "climatic fluctuation and Euroamerican contact" (Owsley, 1985, 1991). For example, climatic fluctuation can reduce crop yield and result in nutritional stress, which if not significantly buffered by the cultural system or the host, can cause cortical bone loss. These relationships are illustrated in the diagram shown in Figure 1.

Owsley's (1985, 1991) previous studies on the Arikara provide a good reference point for gauging what results can be anticipated here. Owsley (1985) reports the

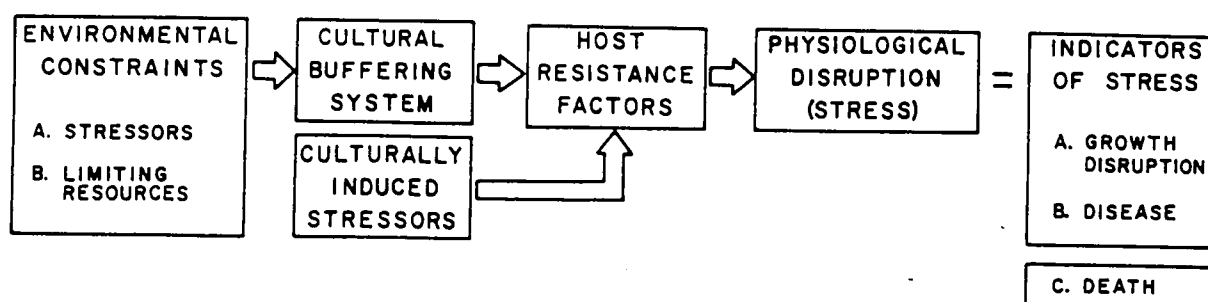


Figure 1. Model for interpretation of stress indicators.

Source: Goodman AH, Martin DL, Armelagos GJ, and Clark G (1984) Indications of Stress from Bone and Teeth. In Cohen MN and GJ Armelagos (eds.): *Paleopathology at the Origins of Agriculture*. New York: Academic Press, pp.13-49.

changes in cortical thickness for South Dakota Arikara during the Coalescent tradition. He argues that increased femoral cortical thickness from the Extended (A.D. 1550-1675) to the Postcontact variant (A.D. 1675-1780) was due to an amelioration of unfavorable climatic influences and the introduction of the horse. He attributes a decline in cortical thickness during the Disorganized variant (A.D. 1780-1860) to an increased incidence of disease and inter-tribal conflict. In a later study Owsley (1991) attributes similar changes in cortical thickness of Plains Indians to the same stressors, yet the results are more temporally precise since they are divided into four time periods. Owsley (1991) finds a rise in cortical thickness during the Late Prehistoric period (A.D. 1600-1650), then a peak in thickness with the start of the Early Protohistoric period (A.D. 1650-1740) and a

decline in thickness, which is especially sharp for females, during the Late Protohistoric period (A.D. 1740-1795).

Diachronic assessment of the Nebraska sites is expected to mirror the temporal changes already demonstrated by Owsley (1985, 1991) for the South Dakota sites. The addition of several South Dakota sites and a North Dakota site to the Northern Plains sample not previously included in Owsley's research is not expected to significantly alter the results. Finally, a small Crow sample is included in the Northern Plains sample.

Hypotheses

The following Plains Indian samples are expected to show different femoral cortical bone indices over time due to varying levels of nutritional stress:

(1) Cortical thicknesses for Central Plains tradition villagers are expected to be small, indicating high levels of nutritional stress. With the gradual increase of bison and decrease of dry weather conditions during the protohistoric period, the Lower Loup phase sample is expected to demonstrate less loss of cortical bone. As time progressed into the Disorganized Coalescent variant, the occurrence of disease and inter-tribal conflict was on the rise and sources of food on the Plains diminished. Therefore, the historic Pawnee individuals should have decreasing cortical thicknesses as evidence of increasing nutritional stress. However, as the location of the Pawnee afforded them some insulation from Euroamerican contact, they probably did not experience the same severity of nutritional stress as their northern neighbors, the Arikara (Owsley, 1996:192).

(2) As discussed above, Owsley (1985, 1991) has already reported the results for the large Coalescent sites in South Dakota. This research expands the data by including a small number of Middle Missouri sites and adding to the group of Coalescent sites.

Despite the addition of these sites, the majority of them are the same ones already studied by Owsley (1985, 1991) so temporal changes in cortical thickness due to changing nutritional circumstances are not expected to vary from those previously demonstrated.

(3) The equestrian nomad sample of Crow Indians is expected to demonstrate significant amounts of nutritional stress through small cortical thickness values. This sample is useful for demonstrating the poor nutritional conditions the Crow were experiencing during the onset of the reservation period.

II. CENTRAL AND NORTHERN PLAINS INDIANS: PREHISTORY AND HISTORY

The following sections outline the archaeological evidence as it relates to the sites and their surrounding regions considered in this research. They detail the reasoning behind the preceding research hypotheses while providing a review of the literature essential to the topic. Typical of investigations of the past, Plains prehistory is far from straightforward, there are many debated elements.

The Plains are typically divided into Northern, Central, and Southern units. The subareas dealt with here are the Central and Northern Plains. The Central Plains extend to the Nebraska-South Dakota border in the north and south to the southern reaches of the Kansas River system (Blakeslee, 1994:12). The northern segment extends north into Canada and south to the Nebraska-South Dakota border.

Blakeslee (1994) relies on Krause (1969:84-87) for the following definitions of the Central Plains (see Fig. 2):

They are the High Plains of western Kansas and Nebraska and eastern Colorado and southeastern Wyoming, the Sand Hills of western Nebraska, the Loess plains of central Nebraska and Kansas, and the Eastern Glaciated region of eastern Nebraska, westernmost Iowa, northeastern Kansas, and northwestern Missouri.

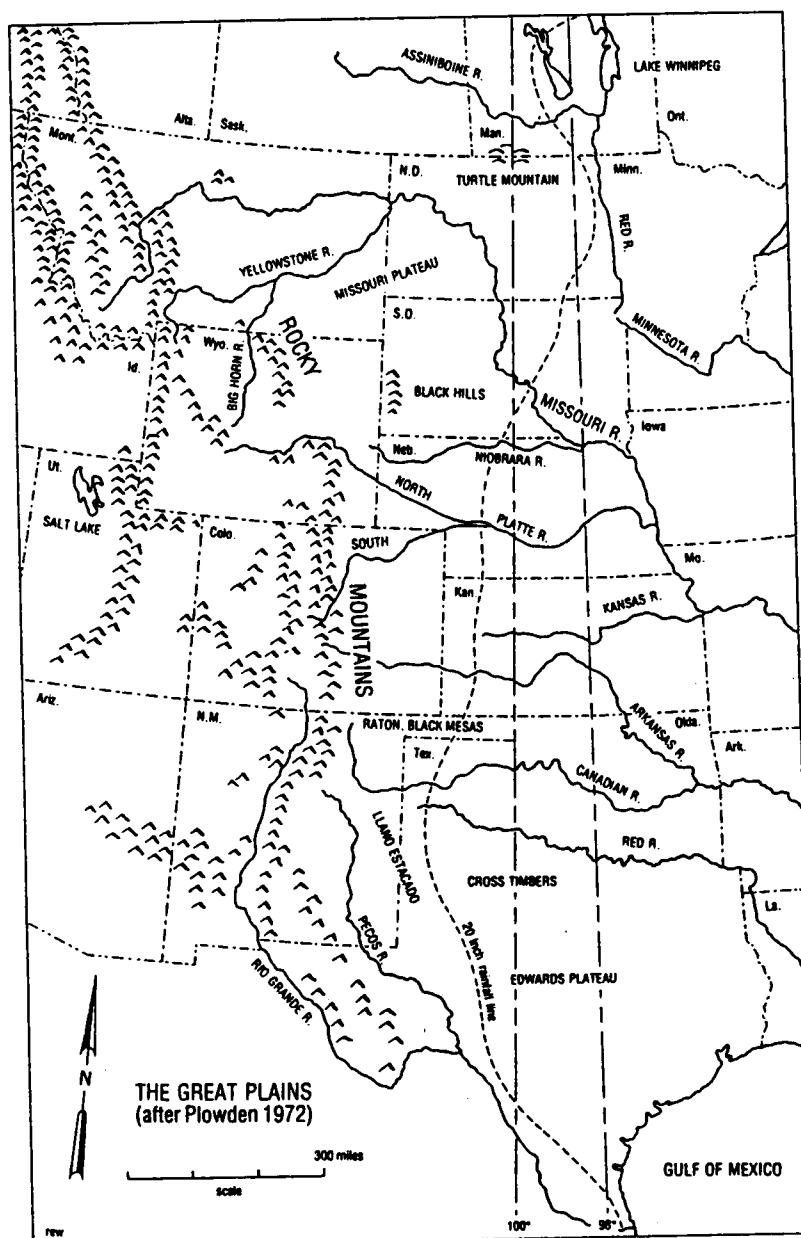


Figure 2. The Great Plains.

Source: Gilbert BM (1980) The Plains Setting. In Wood WR and M Liberty (eds.): Anthropology and the Great Plains. Lincoln: University of Nebraska Press, pp. 8-15.

The Northern Plains can be divided into three sections. These are defined according to the following borders (see Fig. 2):

The Middle Missouri region consists of the trench of the Missouri River from the Nebraska-South Dakota border to the North Dakota-Montana border...Extending west from the Middle Missouri region to the Rocky Mountains and northward into Canada is the Northwestern Plains. The Northeastern Periphery consists of the eastern Dakotas, the western prairie region of Minnesota, and the prairie portions of Manitoba and Saskatchewan (Blakeslee, 1994:12).

The term Central Plains tradition is correctly applied to those

remains south of the Nebraska-South Dakota border and prior to the protohistoric period. The Coalescent tradition includes all the sites that are north of the border and all that are Protohistoric or later, regardless of location (Blakeslee, 1994:15).

Central Plains

Central Plains tradition

The Central Plains tradition (A.D. 1000-1350) is typically viewed as consisting of three different phases or cultures; these are Nebraska, Smoky Hill, and Upper Republican. Upper Republican is sometimes divided into subphases: Solomon River, Classic Upper Republican and Loup River or Itskari (Logan, 1996a:123). St. Helena is less well-known yet important, as it is a transitional phase between the Central Plains tradition phases and the Coalescent tradition (Logan, 1996a:133). Expansion of the Central Plains tradition appears to have moved west from the Missouri River and continued north to the Big Bend region where it ended with the Initial variant of the Coalescent tradition (Roper, 1995:214). The relationship between Central Plains tradition villagers and Initial

Coalescent groups is frequently indicated (Blakeslee, 1993; Roper, 1995). Central Plains tradition sites considered for this research are affiliated with the Nebraska and Itskari phases.

Blakeslee (1994) describes the Arikara and the Pawnee (both Caddoan speakers) as the primary descendants of the Central Plains tradition. Based on cranial evidence, Ubelaker and Jantz (1979) suggest that prehistoric groups such as Upper Republican and St. Helena are possible Pawnee and Arikara ancestors (Jantz, Owsley, and Willey, 1978 in Grange, 1979; Strong, 1935 in Wood, 1965). Ludwickson (1978) points to the continuity of the Loup River phase (Itskari phase) and the protohistoric Pawnee Lower Loup phase arguing that predecessors to the Pawnee never entered the Middle Missouri subarea but remained in the Loup River basin.

According to Logan (1996a), Lehmer (1954b) originally described Central Plains tradition villages as small and unfortified with square or rectangular earthlodges. Villagers of the Central Plains tradition relied on horticulture more intensely than earlier Woodland groups (Johnson and Wood, 1980:38). Evidence of maize, beans, squash, sunflowers, and marsh elder is common (Adair, 1994; Blakeslee, 1994; Wedel, 1986; Johnson and Wood, 1980). Wild plants were also collected and procurement of locally available fauna such as shellfish, birds, and small mammals was also extensive (Bozell, 1995:157; Krause, 1970).

Wedel (1986:123) indicates that hunting bison was probably as important in the subsistence system during this early period as cultivation of maize and other crops, but he believes that hunting was not undertaken on a large scale since the settlements were small and widely dispersed. Hunting probably occurred relatively locally to support the small

communities (Wedel, 1986:126). Bozell (1995) offers a similar scenario citing Osborn (1987:41-45) who indicates that although bison were available to Central Plains tradition villagers, deer were favored over bison and maize. Bozell (1995:157), however, insists that the procurement of deer over bison was due to low availability of bison, not a conscious decision to ignore a cost efficient source of meat.

In general, bison were not nearly as plentiful during the Central Plains tradition as they were in the Middle Missouri region during the same time or during the protohistoric period (Blakeslee, 1994:25; Bozell, 1995:151). Bozell (1995) asserts that the cool, dry conditions created by the Pacific episode (A.D. 1150-1550) would have resulted in drought and poor water and grass quality. The bison herds would have been smaller and had to move more frequently over larger ranges to forage. Bozell (1995) explains that the Pacific episode would have had to begin earlier in some areas (A.D. 1000) in order to account for low bison density found at some Central Plains tradition sites. In addition, very few hunting camps attributed to the Central Plains tradition have been found so it is doubtful that game was killed and processed at sites far from the villages (Bozell, 1995:155). On the other hand, Blakeslee (1993) cautions against relying on climatic change for explaining the depopulation on the Central Plains. He argues that the soil depletion caused by slash and burn horticulture, coupled with population growth, was not only responsible for forcing frequent village relocations, but that it eventually caused the abandonment of Central Plains sites.

Roper (1995:218) also finds evidence supporting depopulation of the major regions of the Central Plains during the fourteenth century resulting in "virtual

abandonment.” The climatic conditions during this period point to an environment in which the Central Plains Indians would have been nutritionally stressed. The Central Plains tradition villagers were either living in dry conditions, which made cultivation difficult, or forced to make frequent relocations due reduced availability of desirable land for slash and burn horticulture. In addition, there was not the same preponderance of bison as was found to the north in central South Dakota or in the later protohistoric period. Sandness and Green (1993) examined human skeletal remains from several Omaha sites in Nebraska and found evidence to support a decrease in nutritional stress over time from the prehistoric to the early contact period. Although this study examined Harris Lines and not cortical thickness, it deserves mention since it estimates the nutritional stress experienced by a St. Helena phase (A.D. 1200-1400) group. It further supports the hypothesis that Central Plains tradition villagers and groups living around the same time were experiencing greater nutritional stress than protohistoric groups.

Evidence from a few sites attests to the poor subsistence base available to the Central Plains tradition villagers indicating that they relied on whatever was readily available, which on occasion may have included other humans (Jantz, pers. comm.; Owsley, pers. comm.). Evidence of possible cannibalism comes from Hill and Cooper (1936) who report that House 2 at the Freemont site (25SY1), which dates to the Nebraska phase, includes a cache pit, presumably the refuse area, where broken and burned human remains from both sexes and a range of ages were recovered along with animal bones. Hill and Cooper (1936) cite reports that detail similar findings. Strong (1935) and Gilder (1926) document other Nebraska phase houses where human remains

were recovered from cache pits and were noted as having been "split in the same manner as are those of animal bones found in the usual house refuse" (Hill and Cooper, 1936:278).

Strong (1935) reportedly argues to the contrary indicating that bodies were stored in the cache pits before their interment (Hill and Cooper, 1936:278). In addition, another author (Cook, 1977 in Owsley and Bruwelheide, 1996) argues that this evidence may point to a charnel house instead of cannibalistic behavior. However, Hill and Cooper (1936) point out that

[s]uch breakage as that executed on the long bones could not have been other than intentional, and it seems hardly reasonable that, if the intention were later to gather them up for burial, so much effort should have been expended in crushing them into minute fragments (Hill and Cooper, 1936:279).

There is not evidence that this was a widespread practice with religious significance or that human flesh was the only available food source, since other animal bones were found with the human ones.

This evidence helps determine the degree of nutritional stress experienced by the Central Plains tradition villagers; cortical thickness for these individuals is expected to be low. Most likely, the Central Plains tradition villagers were unable to meet the subsistence requirements of growing populations and were eventually forced out of the region due to the poor conditions. It is hypothesized that Central Plains populations migrated north to the Middle Missouri subarea where climatic conditions had not been as severe. This "invasion" into the northern territory led to conflicts with the populations already

occupying the area (Blakeslee, 1994; Bozell, 1995). The Central Plains area was not reoccupied until protohistoric times, about A.D. 1600.

Lower Loup phase

Protohistoric groups ancestral to historic Pawnee are most commonly identified with the Lower Loup phase, located on the Loup River in central Nebraska. Grange (1979:141) estimates this phase began about A.D. 1550 and lasted until the historic Pawnee period which began in A.D. 1750. This phase also belongs to the Postcontact Coalescent variant which accurately refers to the time after which Euroamericans arrived in North America but before there is any direct and frequent contact between Native Americans and Euroamericans (Logan, 1996b). Other complexes belonging to the protohistoric period on the Central Plains include Dismal River (Wedel, 1986) and Redbird (Wood, 1965).

Although the ancestry of the Central Plains tradition villagers to Lower Loup groups is debated (cf. Roper, 1993; Steinacher et al., 1991 in Logan, 1996b), the biological and cultural affinity of Lower Loup and historic Pawnee is not. The Lower Loup phase is described by Wedel (1986:153) as the "high-water mark of Pawnee culture." Typically, the Pawnee are described as being subdivided into four bands. The Skidi or Skiri Band is associated with the Lower Loup phase while the Grand Pawnee are identified with occupations near Shell Creek, Skull Creek, and south of the Platte River (Grange, 1979:139). Thus, "both Skidi and Grand Pawnee can be traced into

protohistoric times by the archaeological evidence while the Republican and Tappage appear to emerge in the historic period" (Grange, 1979:137).

Lower Loup phase lifeways appear to have been similar to those of the historic Pawnee. They dwelled in circular earthlodges in semi-permanent villages while subsisting on horticulture (corn, beans, squash, and sunflowers), hunting bison and gathering wild plants (Wedel, 1986; Logan, 1996b).

Bozell (1995:147-155) argues that after A.D. 1600 the intensity with which groups engaged in bison hunting increased from the previous prehistoric period. He attributes an increase in hunting to climatic changes brought on by the Neo-Boreal episode that occurred about A.D. 1550. Bozell (1995:155) explains that "large, slow moving bison herds predictable to hunting parties" were the expected result of warm and moist conditions attributed to the Neo-Boreal episode. His investigation reveals that bison bone density is much higher and faunal diversity is lower for protohistoric Lower Loup sites when compared to faunal remains found at earlier Central Plains tradition sites. Furthermore, bison hunting camps dating to the protohistoric period found in the region are much more common than those dating to earlier sites. Roper (1992) cites documentary evidence indicating that seasonal (i.e. summer and winter) long term hunts occurred by at least the seventeenth century and before regular use of the horse.

Based on this evidence, it is expected that individuals from the protohistoric Lower Loup phase sites experienced the least amount of nutritional stress and will therefore have higher values of cortical thickness when compared with earlier Central

Plains tradition villagers and later historic groups, as evidence points to increasing nutritional stress for the Pawnee.

Disorganized Coalescent variant

The historic period meant a decline of culture and “[a]s with neighboring Plains tribes, the story becomes one of steadily diminishing territory for hunting grounds and residence as white power and thirst for land expanded” (Wedel, 1986:155). The Pawnee were removed from Nebraska in 1876. However, until this point, basic Pawnee lifeways continued in a similar manner to those of their protohistoric ancestors. Wedel (1986:164) speculates that the crop yields for the Pawnee in historic times would have been higher than for their prehistoric predecessors. This may have been due to less drought-like conditions in the Pawnee region which was located east of the territory occupied by their predecessors. However, the more significant contrast from the earlier Plains Village period was a greater reliance on bison hunting.

[T]he Pawnee system of hunting versus horticulture had undoubtedly changed significantly between ca. 1600 and 1800, with the chase assuming an increasingly important role...food shortages following either a serious crop failure or an unsuccessful communal hunt meant much discomfort and sometimes acute suffering or even starvation for the community...the availability of and successful search for wild roots and tubers could become matters of prime importance for human survival (Wedel, 1986:163).

As was previously described, the seasonal schedule of hunting and harvesting was in place for Plains tribes long before the arrival of the horse (Lehmer, 1963; Roper, 1992;

Wedel, 1986). Bison and other large game were pursued during the summer and winter. The groups returned to their villages during the spring and fall to plant and harvest their crops.

As Wedel (1986) describes in the above example, the increased reliance on hunting did not come without problems. Larger populations, and a greater reliance on horses, prevented the Pawnee from having year round settlements since they had to keep moving to find adequate pasturage for grazing horses and resources sufficient for their own survival (Wedel, 1986:163). Will and Hyde (1917:58) also point out that as the Pawnee, Omaha, and Ponca spent much of the year away from their permanent villages pursuing buffalo, whereas the Arikara, Mandan, and Hidatsa did not spend as much time away from their villages. Roper (1992:364) argues that hunting ranges changed over time, increasing during the first half of the eighteenth century and then decreasing due to claims by other tribes and perhaps smaller bison populations.

Bozell (1995) finds low bison bone density at historic Pawnee sites for which he provides several possible reasons. First, with increased use of the horse, bison kills may have occurred at greater distances from the village, resulting in less bone carried back to the village (Bozell, 1995:155). In addition,

[l]ow bison density values at late Pawnee villages such as Linwood may reflect nomad-Pawnee competition for herd access. These conflicts, accompanied by disruptions from disease and eventually direct Euroamerican contact, ultimately led to the collapse of the successful adaptation the protohistoric villagers had developed around bison hunting (Bozell, 1995:159).

Although the Pawnee felt the pressure from nomadic tribes such as the Sioux, and they faced the problems of disease and those related to Euroamerican contact, the

resulting affects were not as negative as they were for their Arikara neighbors to the north.

The Pawnee also did not participate in trade with other tribes or Euroamericans to the extent that the Arikara did (Will and Hyde, 1917:60). To a degree, this protected the Pawnee against disease and theft by equestrian tribes. Smallpox did decimate the Pawnee in 1831, and they were affected by some earlier incidences of disease, but the Vaccination Act of 1832 prevented further occurrences for the Pawnee and other tribes. The Arikara and other tribes along the Upper Missouri River were not vaccinated and as a result they suffered more losses (Trimble, 1994). While the Pawnee may have been more insulated than the Arikara, they still experienced greater nutritional stress than their protohistoric ancestors and cortical bone indices for this sample are expected to reflect this.

Northern Plains

Middle Missouri Tradition

The Middle Missouri tradition dates to the same time (A.D. 900-1675) as the Central Plains tradition. It can be divided into three variants: Initial, Extended, and Terminal. Only a small sample of Initial Middle Missouri variant sites are considered here. Blakeslee (1994:17-18) explains that the descendants of the Middle Missouri tradition are credited with eventually leading to the Mandan and Hidatsa of North Dakota. Expected cortical thickness results should indicate more favorable nutritional conditions compared

with Central Plains tradition villagers but less favorable when compared with the samples from the Extended and Postcontact Coalescent variants.

In general, the Middle Missouri tradition villagers would have shared similar lifeways with those of the Central Plains tradition villagers to the south. There were, however, several differences. According to Bozell (1995:151) although there is evidence of cool, dry conditions in the Middle Missouri subarea due to the Pacific episode, bison populations were not as negatively affected as they were in the Central Plains for reasons which are not yet entirely understood. In addition, evidence of fortification is found at early, southern Middle Missouri tradition sites (Blakeslee, 1994; Lehmer, 1954a; Winham and Lueck, 1994). Blakeslee (1993; 1994:24) suggests that the non-existence of fortifications in the Central Plains, and their existence in the Middle Missouri area, is evidence of land that was less appropriate for slash and burn horticulture in the Middle Missouri region which prompted competition for favorable land and resulted in fortifications. Fortified sites are also believed to be a function of a northern migration/invasion of ancestral Arikara into South Dakota (Blakeslee, 1993; 1994; Roper, 1995). Finally, villages are larger in the Middle Missouri subarea than in the Central Plains. Bozell (1995:159) attributes this to less severe climatic conditions due to the Pacific episode in the northern Plains.

Extended Coalescent variant

The emergence of the Coalescent tradition is characterized as a fusion of the Central Plains and Middle Missouri traditions around A.D. 1450 (Lehmer, 1954a; Lehmer and Caldwell, 1966).

The coalescence of Middle Missouri and Central Plains traits seems to have taken place in the southern part of the Middle Missouri area. The new complex presumably spread upriver from there, and also back into the Central Plains when the area was reoccupied (Lehmer, 1954b:147).

Winham and Lueck (1994:170) suggest northward movement by the ancestors of the Arikara began as early as A.D. 1300 from the Central Plains. Others agree with a date of ca. A.D. 1300 as an accurate beginning point for the Initial variant of the Coalescent tradition (Toom, 1992; Zimmerman et al., 1981 in Toom, 1992:126). The literature generally points to drought conditions in the Central Plains as the motivation for the Arikara's ancestral populations to move northward where more favorable temperatures allowed for horticulture and larger bison populations (Bozell, 1995; Owsley, 1981; Roper, 1992). However, Blakeslee (1993) questions this explanation as there is not evidence supporting it.

Nevertheless, this northward migration belongs to the earliest variant of the Coalescent tradition, the Initial Coalescent. The northward movement of ancestral Arikara is more accurately termed an invasion since one difference from the Central Plains tradition is a marked increase in warfare (e.g. the Crow Creek massacre; Blakeslee, 1994). With a few exceptions, there is somewhat of a reversion to a Central Plains pattern of

settlement (widely spaced and unfortified) during the Extended Coalescent (A.D. 1550-1675), indicating a decrease in warfare (Blakeslee, 1994:17; Owsley, 1991).

It was during the Extended variant of the Coalescent tradition that the village cultures begin to take hold of the Middle Missouri region of South Dakota. In general, Plains Indians maintained a mixed economy which included cultivation of corn, beans, squash, and sunflowers, gathering wild plants, and hunting (Owsley, 1985; 1991). Although there is evidence of growth and increasing control of the Middle Missouri Valley, there were probably periods of nutritional disadvantages due to negative influences on the environment caused by the cooler and moister conditions brought on by the Neo-Boreal climatic episode which lasted from A.D. 1550 until about A.D. 1850 (Jantz and Owsley, 1984; Owsley, 1985;1991). This most likely was responsible for decreased crop yields evidenced in fewer cache pits and smaller and shorter occupations. Only a few sites used in this research date to the Extended Coalescent. However, results are expected to follow the trends already reported by Owsley (1985; 1991). Thus, there should be a rise in cortical thickness values when compared to sites dating earlier yet they should be lower than the values for Postcontact Coalescent sites.

Postcontact Coalescent variant

During the Postcontact Coalescent variant there is evidence of marked cultural expansion; settlements are larger and more permanent. This is attributed to a lapse in the unfavorable conditions caused by the Neo-Boreal (Owsley, 1991:109). Higher crop yields during this time provided protection against less productive seasons and allowed for trade

with other groups (Jantz and Owsley, 1984:16). In addition, the acquisition of the horse during the early or middle of the eighteenth century (dates vary) provided further opportunities for trade and hunting. However, Owsley (1991:109) asserts that "the major change (improvement) in Postcontact period nutritional status preceded the arrival of the horse." The improvement in conditions is clearly evident in an increase in cortical thickness during the Extended variant and its peak during the Postcontact variant (Owsley, 1985; 1991).

As the Early Protohistoric period continued the number of problems increased for the Arikara. "Due to disease and warfare with the Dakota, Deetz viewed the period of 1720-1750 as the time of greatest stress for the Arikaras" (Deetz, 1965 in Rogers, 1990:81). Although this may have been a significant period of stress for the Arikara it was not the end to their difficulties for there was no alleviation of problems in the period that followed.

Disorganized Coalescent variant

The Arikara continued to live in villages and practice horticulture and seasonal communal hunting to the degree that it was possible. Northern Plains communities were met with mounting problems during the Late Protohistoric and Historic period (Owsley, 1991). Climatic events such as drought and floods affected crop yields and available grassland for bison herds (Owsley and Bruwelheide, 1996). Like the protohistoric sites, all the historic Arikara sites are located in South Dakota; one exception is the Greenshield site (32OL17) in North Dakota which is a Historic Arikara site.

The location of Arikara villages along the Missouri River afforded them the role of middlemen in the trade network between other tribes and Euroamericans (Rogers, 1990). Since, they supplied corn to fur traders and equestrian tribes, Wood (1980:106) suggests that this may have encouraged a more heavy reliance on maize production by tribes such as the Arikara in order to produce surplus crops for trade.

The few positive effects from European presence such as the horse and trade opportunities were quickly outweighed by exposure to diseases such as measles, smallpox, cholera, and whooping cough, which became epidemic in proportion (Owsley, 1985:201). A survey of the literature provides an estimate of at least ten epidemics on the Upper Missouri between 1772-1857 (Rogers, 1990:82). The shrinking size of populations such as the Arikara and the Pawnee made them easy targets for raids by the nomadic equestrian groups (Jantz and Owsley, 1984a:16). The contents of cache pits were stolen and horticultural and hunting efforts were slowed and even halted due to the threat of attacks (Hurt, 1969:32; Owsley, 1985:202).

Not only were the Arikara met with external hostilities but "factionalism resulting from village agglomeration must have been an increasingly important problem" (Rogers, 1990:84). In fact, there is evidence of "a decline in centralized authority at the Leavenworth site" based on an examination of burial practices (O'Shea, 1978:136 in Rogers, 1990:84). Thus, the Arikara were forced to contend with both internal and external problems. The resulting food shortages and the presence of disease took their toll on the health of the Indians and hindered their ability to resist the effects of nutritional

stress as efficiently. The significant decline in cortical thickness and enlarging medullary cavities is readily apparent in Owsley's (1985;1991) reports.

Crow

The Crow are characterized as a nomadic equestrian tribe.

The decline of the village cultures in the latter half of the eighteenth century was balanced by the rise of a new climax in the Northern Plains, the climax which distinguishes the Equestrian Horizon from its predecessors. This was the culture of the mounted bison hunters of historic times, of the...Crow... (Lehmer, 1954b:154).

Unfortunately, the skeletal sample of Crow examined in this research, which dates to the reservation period (ca. 1870-1900), is small (N=7). It is included to provide an idea of the effects of severe nutritional stress on cortical thickness experienced by the Crow.

Although there is not a precise site with which the remains of the Crow individuals are associated, they were all recovered from the same locality (Owsley, pers. comm.). The location of the Crow territory ca. 1855-1856 roughly covered the region outlined by the Powder, Wind, Yellowstone and Muscleshell Rivers in Wyoming and Montana (Denig, 1961:139). The Crow reservation is now located near Billings, Montana within the same territory they once occupied (Oswalt, 1988).

According to Lehmer (1954b), due to the horse, bison hunting was of primary importance for equestrian tribes; however, they acquired maize through trade with horticultural villagers and by raiding their cache pits (Jantz and Owsley, 1984; Katz et al., 1975). However, raiding for horses among the equestrian groups was much more

common since possession of horses was a measurement of wealth . Denig (1961:146-147) reports that raids for horses between the Crow and Blackfeet (and other tribes such as the Assiniboin and Sioux) occurred practically daily. The smaller size of the Crow tribe often made them a prime target for raids by other tribes.

Just as raiding for horses was a central activity in Crow life, the hunt for bison was also primary. An ethnographic report of the Crow from 1856 provides this description:

Owing to their having good animals and plenty of them the Crow seldom suffer for want of meat as is the case with some tribes who are not so well furnished with horses. They can move camp at any time and go in quest of buffalo, should there be none in the neighborhood. They have little else to eat but meat. Their country produces a few wild cherries, plums, and service berries, together with some esculent roots. But none of these are collected in sufficient quantities to form a resource in time of need, and as they do not cultivate, they depend entirely on the chase for subsistence (Denig, 1961:160).

Although the nomadic hunting existence of the Crow may have been at times challenging when bison were scarce, it also put them at an advantage. Equestrian groups were not as vulnerable to the threat of disease as the horticulturalists who were living closely grouped together in their villages. Even though horticultural groups still hunted seasonally, their lifestyle required cooperation among everyone in the village for planting and harvesting (Trimble, 1994). In addition, the villagers were in contact more often with other tribes and Euroamericans for trading purposes.

In contrast, the nomadic groups visited trading posts but did not live in close proximity to them. Their nomadic life insured fewer contacts with potential pathogens. The smaller number of inhabitants housed in their portable living quarters, as well as their ability to disperse, provided fewer chances for the spread of an acute infection (Trimble, 1994:86).

The smallpox epidemic of 1837-1838, among other epidemics, virtually destroyed the village horticulturalists in the Upper Missouri region. This allowed the equestrian groups to gain power as they were not as devastated (Trimble, 1994). The power reign was not long lasting, however. As bison herds diminished and eventually disappeared in the early 1880's and disease and severe winters took its toll on horses and tribes, an existence based solely on the hunt was impossible to continue (Ewers, 1943:606). Tribes were force to depend on the government for survival (Oswalt, 1988). Low cortical thickness values are expected to reveal the nutritional stress experienced by the Crow as traditional lifeways were lost by forced reservation living.

Summary

After having presented the archaeological evidence, the research hypotheses can be reviewed. The Central Plains archaeological variants are expected to show an increase in cortical bone thickness measurements between the Central Plains tradition and Lower Loup phase as there was an improvement in climatic conditions and increase in bison populations. From the Lower Loup phase to the Disorganized Coalescent (Pawnee), there should be a decrease in cortical bone thicknesses due to a rise in inter-tribal conflict and in occurrence of disease due to Euroamerican contact.

The Northern Plains are expected to follow the pattern already demonstrated by Owsley (1985, 1991) for the Coalescent tradition sites. A rise between the Extended and Postcontact Coalescent samples is expected due to an amelioration of unfavorable climatic influences. A decrease is expected for the Disorganized Coalescent (Arikara) as disease and inter-tribal conflict impacted the Northern Plains. The Initial Middle Missouri sample is expected to show lower cortical bone indices than the Extended Coalescent variant. Finally, the Crow sample should demonstrate high amounts of nutritional stress as bison herds diminished and adequate sources of food were scarce.

III. CORTICAL BONE REMODELING

It is important to understand the pattern of remodeling for normal bone before the impact of nutritional stress on cortical bone is assessed. As a living tissue bone is not static, it changes throughout all stages of life. The human skeletal system not only supports and protects muscles and organs and allows for movement, it is also responsible for maintaining correct mineral content in body fluids and producing red blood cells (Martin et al., 1985).

Cortical bone forms the dense outer surface of bone, it surrounds the lighter spongy, trabecular or cancellous bone found in spaces of bones such as the marrow cavities at the epiphyses of long bones and the bodies of vertebrae (Stini, 1995). The density of cortical bone results from calcium, phosphates, and carbonate within the matrix which allows it to withstand both tensional and torsional stresses (Martin et al., 1984; Stini, 1995). Whereas cortical bone is constantly being remodeled, typically when trabecular bone is resorbed it is not replaced.

Cortical bone is formed by osteons, or Haversian systems, which are constructed of a blood vessel surrounded by concentric layers of bone called lamellae (Stini, 1995). Nutrients and waste are transported to and from the osteon through canals called canaliculae. Within the Haversian system are spaces called lacunae which contain the actual bone cells or osteocytes. Primary osteons are resorbed entirely or partly and are replaced by secondary osteons. Remodeling of cortical bone does not happen at the same

rate throughout the entire skeleton, different bones and surfaces experience different rates of bone turnover (Stini, 1995).

The surface that has the most rapid rate of remodeling in long bones is the endosteal surface (inner surface). Bone remodeling also occurs on the periosteal surface (outer surface) and within the actual Haversian systems (Stini, 1995). Cells called osteoclasts are activated to resorb bone and osteoblasts are the cells that deposit matrix which is later mineralized (Eriksen et al., 1993). When the Haversian system is completed it is a newly formed cortical bone structural unit (Eriksen et al., 1993). Medullary cavity enlargement occurs when more bone is resorbed than replaced, excessive bone resorption leads to cortical thinning or osteoporosis.

Any type of disturbance in the amount of resorption and formation of bone can cause an imbalance. Two different types of bone loss have been identified and they can occur in both cortical and trabecular bone (Parfitt, 1984). Rapid bone loss in cortical bone results in "endosteal cavitation and conversion of the inner third of the cortex to a trabecular like structure" (Parfitt, 1984:S123). Inadequate osteoblastic refilling of normal resorption cavities is referred to as slow bone loss, the strength of the bone is reduced due to thinning of the cortical structure. As rapid and slow loss bone occurs on the endosteal surface, the bone continues to be deposited on the periosteal surface. This slow deposition on the periosteal surface can partly compensate for the endosteal loss. However, this protection is only temporary, if thinning continues the risk of fracture increases.

Changes in cortical bone are the result of the changes on the subperiosteal and endosteal surfaces. The following summary is based on the work of Garn (1970) and Frisancho et al. (1970) on second metacarpal bone remodeling for populations from the United States and Central America. Cortical bone thickness is found by subtracting the width of the medullary cavity from the total subperiosteal diameter ($C=T-M$; see Fig.3). Throughout life, T increases, and M increases until puberty and then begins to decrease. The medullary cavity continues to decrease until the mid-thirties or forties at which time the process is reversed and it increases again. Therefore, until the forties, C gains in "thickness and area...and then it reverses...due to an age-associated non-linear increase in M, but compensated in part by a slow linear increase in T" (Garn, 1970:10).

Total subperiosteal diameter increases in the form of a "spurt" for both girls and boys with the onset of adolescence. However, this spurt occurs later and is more significant in males. The expectation is that males will exhibit a higher cortical bone index than females because more bone is retained during the adolescent spurt. Like on the subperiosteal surface, endosteal resorption is greater, and occurs later, in males. However, women experience more significant loss of bone on the endosteal surface with age. Comparison of adolescent samples from the United States and Central America have led researchers to suggest that environmental differences in size, nutritional intake, amount of activity, and incidence of disease are not responsible for the onset of endosteal apposition; while responses to hormonal signals are.

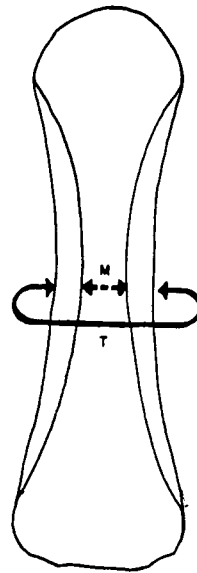


Figure 3. Measurements of subperiosteal diameter (T) and medullary cavity width (M) which are used to find C ($T-M$). Source: Garn SM (1970) *The Earlier Gain and Later Loss of Cortical Bone in Nutritional Perspective*. Springfield, Illinois: Charles C. Thomas.

In summary, the changes of T and M result in an increase in C into and beyond adolescence. The spurt of growth is more pronounced in females for C since it is greater for T and M. However, males experience a more constant gain in cortical thickness and the amount of cortical loss per year is more dramatic in women. Cortical loss begins, for both sexes, in the fourth decade and peaks during the fifth and sixth decades after which loss is not as significant.

Nutrition and Cortical Bone

Disruption in the normal rate and pattern of bone remodeling resulting from malnutrition is evident in decreased cortical thicknesses and particularly due to loss of bone on the endosteal surface. A variety of other reasons can also cause loss of cortical bone for example, disorders such as blood dyscrasias, osteogenesis imperfecta hyperparathyroidism, and malabsorption syndromes result in loss of bone mainly on the endosteal surface (Garn, 1970:54).

Populations that rely heavily on one food type for their subsistence generally experience health problems because important minerals and amino acids are not supplied by a narrow diet. For example, maize is not an adequate source of lysine, tryptophan, or niacin and high intake of corn can result in pellagra (Katz et al., 1975: 198). On the other hand, if populations eat large amounts of meat they run the risk of losing calcium caused by high levels of phosphorous and acid (Richman et al., 1979). Usually, diets are not based so heavily on one food type and are somewhat balanced by the consumption of items such as beans, squash, and other legumes which contain essential nutrients (Katz et al., 1975). Vegetarians demonstrate the least amount of cortical bone loss when compared with omnivores (Mazess and Mather, 1974; Richman et al., 1979).

When malnutrition does occur, it is most noticeable on the endosteal surface. Cortical thickness of metacarpals decreases in children with kwashiorkor and marasmus due, not to the failure to form bone (subperiosteal growth remains close to normal because it is more dependent on caloric sufficiency), but to the actual loss of bone due to excessive endosteal resorption (Garn, 1970; Garn et al., 1969). In addition, evidence points to

continued bone loss during the recovery period (Garn, 1970; Garn, Rohmann, Behar, Viteri, and Guzman, 1964). However, while loss of bone occurs on the endosteal surface, growth and ossification generally are not as affected.

Diagnosed cases of kwashiorkor and marasmus have greatly enlarged marrow cavities, thin skull bones, and fewer trabecular elements in the round bones, without an excessive reduction in outer bone sizes or in ossification timing (Garn, 1970:36).

The work of other researchers attest to these findings (Fleagle et al., 1975; Huss-Ashmore, 1981; Hummert, 1983). Himes et al. (1975) report, however, that comparison of severely malnourished children and moderately malnourished children may not be sufficient for understanding the affects of malnutrition on the subperiosteal surface. Instead, comparison of severely malnourished children and well-nourished children reveals that "chronic protein-calorie deficiency may be a more important factor in retarding periosteal growth than the more acute often rapidly precipitated bout with kwashiorkor" (Himes et al., 1975:347).

Finally, nutritional stress is often more visible on the endosteal surface in females. There are several possible causes, all of which may be applicable. Owsley (1985:205) indicates that the earlier occurrence of apposition on the endosteal surface during adolescence in females may heighten this surface's susceptibility to the negative effects of malnutrition. Other studies suggest the greater labor demands placed on women may be responsible (Sandness and Reinhard, 1992). Finally, the physical stress of pregnancy and lactation may play a role (Martin and Armelagos, 1979).

IV. MATERIALS AND METHODS

Data were collected directly from femoral radiographs of Plains Indians, which are curated at the Department of Anthropology, National Museum of Natural History, Smithsonian Institution. The measurements for the Coalescent sites and some of the Nebraska sites had been previously collected by other researchers. The measurements for the remaining sites were collected by this researcher. Tables 1 and 2 list the sites, archaeological variants, and sample sizes used in this research. The radiographs of the femora were taken in the standard posterior-anterior position with a "Kodak single lanex, fine screen X-omatic cassette and NMB-1 film" (Owsley, 1991:105). Measurements were taken at the midshaft with Mitutoyo Digimatic™ calipers to find medullary cavity width (M) and total subperiosteal diameter (T) to 0.1 mm. Maximum femoral lengths were measured with a standard meter stick. X-rays of both left and right femora were measured if both sides were present. However, during statistical analysis, preference was given to the left if both sides were measured. The Plains Indians in the samples are classified as young adults (16.5-34 years of age). Analysis of this age group is beneficial because the samples are not as affected by the adolescent growth spurt or age-related endosteal resorption. Individuals with anomalies and pathologies were excluded.

Radiogrammetry is a relatively inexpensive, noninvasive method for determining cortical thickness. It does not, however, allow for direct assessment of bone mineral content or density; other techniques such as quantitative computed tomography and the

Table 1. Central Plains sites, date ranges, archaeological phases, and sample sizes (Bozell, pers. comm.; Key, 1983; Owsley, pers. comm.).

SITE	NAME	DATE RANGE	PHASE	N
CPT¹				
25CC1	Ashland	(1000-1350)	Unknown	M=0 F=1
25HW2	Lehn	1250-1450	Itskari	M=0 F=2
25HW3	Sondergaard	1250-1450	Itskari	M=0 F=3
25HW6	Coufal	(1000-1350)	Itskari	M=0 F=3
25HW8	Christensen	1250-1450	Itskari	M=0 F=4
25NC13	Wozney	(1000-1350)	Itskari	M=2 F=3
25WN3	Kelly	1050-1400	Nebraska	M=3 F=3
LLP				
25BU4	Barcal	(1550-1750)	Lower Loup	M=0 F=1
25CX1	Gray/Schuyler	1650-1675	Lower Loup	M=0 F=1
25NC1	Burkett	1530-1780	Lower Loup	M=1 F=2
25NC3	Wright	1580-1780	Lower Loup	M=2 F=6
25PT13	Hill-Rupp	(1550-1750)	Lower Loup	M=1 F=0
25PT31	Christman	(1550-1750)	Lower Loup	M=0 F=1
DC				
25BU1	Linwood	1777-1809	Historic	M=2 F=3
25BU2	Bellwood	(1780-1860)	Historic	M=0 F=1
25NC20	Genoa	1857-1873	Historic	M=0 F=4
25NC23	?	(1780-1860)	Historic	M=1 F=0
25PK1	Clarks	(1780-1860)	Historic	M=6 F=2
25WT1	Hill/Pike	1775-1815	Historic	M=2 F=2

1. CPT, Central Plains tradition; LLP, Lower Loup phase; DC, Disorganized Coalescent. Date ranges in parentheses are phase ranges, specific dates are unavailable.

Table 2. Northern Plains sites, date ranges, archaeological phases, and sample sizes (Bass et al., 1971; Key, 1983; Owsley, 1981; 1985; 1991).

SITE	NAME	DATE RANGE	PHASE	N
IMM¹				
39DV2/3	Mitchell Mounds	1033-1105	Over	M=2 F=0
39HS1	Bloom Village	900-1400	Over	M=2 F=1
39HT1	Twelve Mile Creek	1041-1135	Over	M=0 F=1
39LM2(A)	Medicine Creek	900-1400	Grand Detour	M=1 F=0
EC				
39CA4	Rygh	1600-1650	La Roche	M=5 F=4
39SL4	Sully A, D	1650-1694	La Roche	M=7 F=10
39WW1	Mobridge 1, 3	1600-1650	La Roche	M=9 F=9
PC				
39DW2	Four Bear	1758-1774	Le Beau 2	M=1 F=6
39HU2	Oahe Village	1650-1725	Le Beau 1	M=4 F=0
39LM33	Dinehart Village	1725-1760?	Unknown	M=2 F=2
39SL4	Sully B, E	1679-1733	Le Beau 1	M=7 F=6
39ST1	Cheyenne River	1740-1795	Bad River 2	M=2 F=7
39ST235	Stony Point	1740-1795	Bad River 2	M=1 F=2
39WW1	Mobridge 2, 4	1675-1700	Le Beau 3?	M=5 F=14
39WW2	Larson	1679-1733	Le Beau 3	M=22 F=32
39WW7	Swan Creek	1675-1725	Le Beau 2	M=9 F=6
DC				
32OL17	Greenshield	ca. 1800-1830	Historic Arikara	M=3 F=2
39CO9	Leavenworth	1802-1832	Historic Arikara	M=12 F=11
39ST215	Leavitt	1784-1792	Bad River 2	M=3 F=1
EQ				
(No site)	Crow	ca. 1870-1900	Reservation	M=3 F=2

12. IMM, Initial Middle Missouri; EC, Extended Coalescent; PC, Postcontact Coalescent; DC, Disorganized Coalescent; EQ, Equestrian nomads.

absorptiometry methods (single-photon, dual-photon, dual energy x-ray) are preferred (Faulkner et al., 1991).

Garn (1970:7) finds that measuring M and T at the femoral midshaft presents a problem due to the linea aspera; "calculations of subperiosteal area and cortical area inadequately describe the bone in cross-section if only the A-P projection is employed." Typically in studies of cortical bone thickness, the second metacarpal is preferable for taking cortical measurements due to its relatively low morphological variability (Garn, 1970:125). This possible limitation is noted; however, since the samples are archaeological, use of femora is preferred. Furthermore, previous studies have not reported any problems regarding the use of femora and the linea aspera (Owsley, 1985; 1991).

Another concern is the genetic component involved with the rate of T, the size of M, and thus C (Garn, 1970:20, 38). In Owsley's (1985) examination of the Arikara, the role of genetics is controlled to a degree. In this study different populations are compared preventing control of this factor. Garn (1970:58) concedes, however, that "[m]ost of the population differences we have studied may be attributed more to the total caloric intake than to genetic differences." Variation of maximum length measurements are expected to demonstrate population differences since malnutrition is not linked to preventing ossification. Although differences are recognizable when ethnic groups are compared (e.g., Garn, Pao, and Rihl, 1964), hopefully the role of genetics will be minimal in this research.

The statistical software SAS® is used for the comparison of T, M, and C (T-M) for the different populations, as they reveal much about the rates of apposition and resorption on the subperiosteal and endosteal surfaces. Further manipulation of the measured variables with SAS® provides additional values for comparison. Nordin's score ($NS=T-M/T$) is a two-dimensional expression of how much of the total diameter is cortex; it is found by dividing the cortical thickness by the total subperiosteal diameter (Garn, 1970:11). In addition, small changes that occur in T and M affect total subperiosteal area [$TA=\pi(T/2)^2=0.785T^2$] and medullary cavity area ($MA=0.785M^2$), which is simplified the same way, and are therefore more noticeable in cortical area $CA=0.785(T^2-M^2)$. "Area rather than diameter most realistically describes changes in the three-dimensional bone" (Garn, 1970:73; See Fig. 4). Owsley (1991:106) admits this variable assumes that the bone has a cylindrical shape, but this is not entirely accurate for the femur. However, analysis of this variable remains useful as it indicates "absolute bone mass" (Owsley, 1991:106).

SAS® was used to find the means and standard deviations for the each of the variables and variants and for both sexes. SAS® was then instructed to use the general linear models analysis of variance for each of the variables by archaeological variant and sex to find sample differences (Littell et al., 1991). Duncan's multiple-range test was used with the general linear models procedure to gain a better idea of which variant means are significantly different from the others (Littell et al., 1991). Duncan's test groups the means which are not significantly different from each other, but groups can overlap and the results are often too general since the results show multiple comparisons, not

particular comparisons. Duncan's test is useful, however, when one mean is assigned its own group due to a significant difference from the others. In order to specifically target significant differences between variants for each variable, contrasts or comparisons of variants, already planned in the research hypotheses, were included in the general linear models procedure.

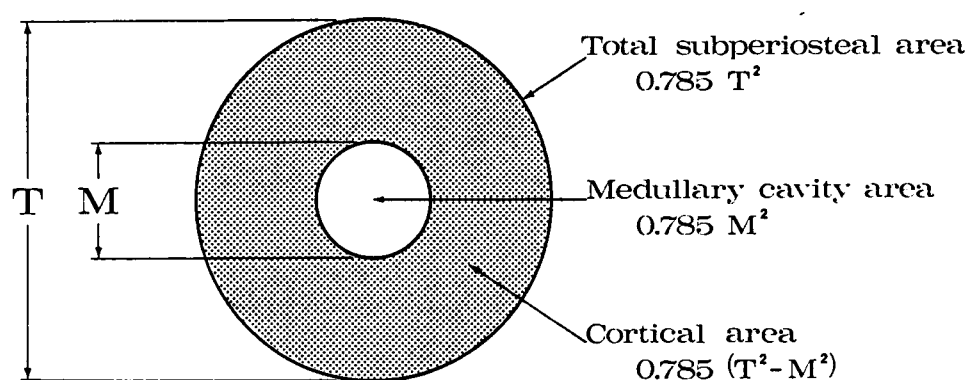


Figure 4. Total subperiosteal area, medullary area and cortical area as derived from T and M. Source: Garn SM (1970) *The Earlier Gain and Later Loss of Cortical Bone in Nutritional Perspective*. Springfield, Illinois: Charles C. Thomas.

V. RESULTS AND DISCUSSION

The sample sizes, means and standard deviations for the variables and archaeological variants with sexes pooled are presented in Table 3. Means and standard deviations are presented by sex and archaeological variant in Tables 4 and 5. The results of the general linear models analysis of variance by sex and archaeological variant are presented in Table 6. It is worth noting that none of the interactions between sex and variant are significant.

As expected, differences between males and females are highly significant for maximum femoral length. Sex differences are also highly significant for the variables M, T, C, and CA. What is more relevant, are the expected temporal differences for the variables. The results in Table 6 show that differences for the archaeological variants are highly significant for medullary cavity width, total subperiosteal diameter, cortical thickness, Nordin's score, and cortical area. No temporal difference is noted for maximum length.

As explained in the previous section, Duncan's test was used in the general linear models procedure to clarify the relationships of the variant mean differences. As these results were ambiguous, specific contrasts of variants were included in the general linear models procedure as well. When variant contrasts were included in the general linear models procedure, only archaeological variants were used in the model since the

Table 3. Means and standard deviations for femoral cortex and maximum length measurements for each archaeological variant.

Variable ^a	Central Plains Tradition		Lower Loup Phase		Pawnee-Diorg. Coal.		Initial Middle Missouri	
	N	Means	N	Means	N	Means	N	Means
M	24	11.03	15	11.97	23	12.67	7	10.63
T	24	24.26	15	25.95	23	26.23	7	27.11
C	24	13.23	15	13.99	23	13.56	7	16.49
NS	24	0.54	15	0.54	23	0.51	7	0.61
CA	24	369.01	15	418.51	23	416.24	7	487.07
ML	9	430.00	7	444.29	17	452.18	6	476.67
Extended Coalescent								
M	44	11.88	128	11.20	32	12.83	5	13.80
T	44	25.26	128	25.28	32	26.53	5	25.96
C	44	13.38	128	14.08	32	13.70	5	12.16
NS	44	0.53	128	0.56	32	0.52	5	0.47
CA	44	390.65	128	404.04	32	423.28	5	381.43
ML	39	442.36	114	445.15	32	455.03	5	465.20
Postcontact Coalescent								
M	44	11.88	128	11.20	32	12.83	5	13.80
T	44	25.26	128	25.28	32	26.53	5	25.96
C	44	13.38	128	14.08	32	13.70	5	12.16
NS	44	0.53	128	0.56	32	0.52	5	0.47
CA	44	390.65	128	404.04	32	423.28	5	381.43
ML	39	442.36	114	445.15	32	455.03	5	465.20

a. M, medullary cavity diameter; T, total subperiosteal diameter; C, cortical thickness; NS, Nordin's score; CA, cortical area; ML, maximum length.

Table 4. Means and standard deviations for the Central Plains sites for femoral cortex and maximum length measurements by sex and archaeological variant.

Maximum length measurements by sex and archaeological variant.									
Variable ^a	Central Plains tradition			N	Lower Loup phase		Disorganized Coalescent		
	N	Mean	S.D.		Mean	S.D.	N	Mean	S.D.
MALE									
M	5	11.82	0.70	4	11.73	0.39	11	13.67	1.86
T	5	25.60	2.13	4	27.60	2.19	11	27.88	1.48
C	5	13.78	2.10	4	15.88	2.20	11	14.21	2.24
NS	5	0.54	0.04	4	0.57	0.04	11	0.51	0.07
CA	5	407.33	86.26	4	492.81	94.18	11	462.59	71.05
ML	2	459.00	18.38	2	459.00	15.56	8	468.88	23.28
FEMALE									
M	19	10.82	1.32	11	12.05	1.48	12	11.76	1.20
T	19	23.91	2.12	11	25.35	1.86	12	24.73	2.18
C	19	13.09	2.26	11	13.30	1.67	12	12.97	2.53
NS	19	0.55	0.06	11	0.52	0.05	12	0.52	0.07
CA	19	358.92	76.69	11	391.49	64.06	12	373.76	85.06
ML	7	421.71	10.59	5	438.40	31.03	9	437.33	24.88

a. M, medullary cavity diameter; T, total subperiosteal diameter; C, cortical thickness; NS, Nordin's score; CA, cortical area; ML, maximum length.

Table 5. Means and standard deviations for the Northern Plains sites for femoral cortex and maximum length measurements by sex and archaeological variant.

Variable ^a	Initial Middle Missour			Extended Coalescent			Postcontact Coalescent			Disorganized Coalescent			Crow		
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
MALE															
M	5	11.48	1.98	21	12.44	1.67	53	12.22	1.69	18	13.28	1.94	3	14.80	1.54
T	5	27.38	1.98	21	26.30	1.87	53	27.02	1.58	18	27.67	1.34	3	27.73	1.31
C	5	15.90	1.86	21	13.86	1.33	53	14.81	1.56	18	14.39	1.89	3	12.93	0.31
NS	5	0.58	0.06	21	0.53	0.04	53	0.55	0.05	18	0.52	0.06	3	0.47	0.03
CA	5	485.04	71.13	21	422.04	56.45	53	455.79	56.33	18	461.01	55.50	3	431.48	21.66
ML	4	476.75	12.84	18	460.44	15.41	46	471.78	22.00	18	471.33	23.67	3	475.00	19.97
FEMALE															
M	2	8.50	1.41	23	11.37	1.57	75	10.48	1.78	14	12.24	1.74	2	12.30	2.26
T	2	26.45	1.06	23	24.31	1.35	75	24.05	1.63	14	25.06	1.42	2	23.30	1.56
C	2	17.95	2.47	23	12.94	1.54	75	13.57	1.59	14	12.82	1.47	2	11.00	0.71
NS	2	0.68	0.07	23	0.53	0.06	75	0.57	0.06	14	0.51	0.06	2	0.47	0.06
CA	2	492.13	62.92	23	361.98	45.65	75	367.46	50.80	14	374.76	46.44	2	306.35	13.21
ML	2	449.50	4.95	21	426.86	17.86	68	427.13	16.02	14	434.07	18.06	2	450.50	26.16

a. M, medullary cavity diameter; T, total subperiosteal diameter; C, cortical thickness; NS, Nordin's score; CA, cortical area; ML, maximum length.

Table 6. Two way analysis of variance of femur measurements by archaeological variant and sex.

Variable	Source	DF	Sum of Squares	F	PR > F
M	Model	15	298.18	7.14	0.0001
	Sex	1	55.53	19.95	0.0001
	Variant	7	111.12	5.70	0.0001
	Interaction	7	21.59	1.11	0.3583
	Error	262	729.36		
	TOTAL	292	1215.78		
T	Model	15	593.35	14.04	0.0001
	Sex	1	157.05	55.73	0.0001
	Variant	7	62.24	3.16	0.0032
	Interaction	7	21.74	1.10	0.3621
	Error	262	738.32		
	TOTAL	292	1572.70		
C	Model	15	208.16	4.65	0.0001
	Sex	1	25.81	8.65	0.0036
	Variant	7	105.35	5.04	0.0001
	Interaction	7	24.25	1.16	0.3258
	Error	262	782.13		
	TOTAL	292	1145.70		
NS	Model	15	0.16	3.33	0.0001
	Sex	1	0.00	0.92	0.3380
	Variant	7	0.14	6.05	0.0001
	Interaction	7	0.02	1.09	0.3731
	Error	262	0.86		
	TOTAL	292	1.18		

NOTE: Sum of squares for sex, variant, and interaction are Type III. Variable abbreviations are listed with Table 3.

Table 6 (continued).

Variable	Source	DF	Sum of Squares	F	PR > F
CA	Model	15	550478.50	10.53	0.0001
	Sex	1	1 37011.32	39.32	0.0001
	Variant	7	84972.29	3.48	0.0014
	Interaction	7	25837.70	1.06	0.3904
	Error	262	913039.86		
	TOTAL	292	1711339.67		
ML	Model	15	95885.10	17.23	0.0001
	Sex	1	19214.00	51.79	0.0001
	Variant	7	4226.16	1.63	0.1290
	Interaction	7	2343.54	0.90	0.5055
	Error	262	79022.83		
	TOTAL	292	200691.63		

NOTE: Sum of squares for sex, variant, and interaction are Type III. Variable abbreviations are listed with Table 3.

interaction between sex and variants was previously demonstrated as not significant.

Contrasts are preplanned comparisons based on the structure of the research hypotheses, and not determined by the data, so they are better equipped to determine which variant differences are significant for each variable (Littell et al., 1991).

In general, the variables were expected to demonstrate significant differences from each archaeological variant to the next. The same contrasts were used for each variable based on the hypotheses delineated in the chapters above, they are as follows: Central Plains tradition vs. Lower Loup phase; Lower Loup phase vs. Disorganized Coalescent-Pawnee; Initial Middle Missouri vs. Central Plains tradition; Initial Middle Missouri vs. Extended Coalescent; Extended Coalescent vs. Postcontact Coalescent; Postcontact Coalescent vs. Disorganized Coalescent-Arikara; Protohistoric (Lower Loup phase and Postcontact Coalescent) vs. Historic (Disorganized Coalescent-Arikara and Pawnee); Postcontact vs. Crow; Disorganized Coalescent (Arikara and Pawnee) vs. Crow. The results of these contrasts for each variable are presented in Table 7.

Figure 5 illustrates the general expectation that the means for M for the earlier archaeological variants are lower than those of the more recent variants. The expected increase in medullary cavity width between the Postcontact variant and the Disorganized Coalescent samples is shown. Another rise between these variants and the Crow sample further supports the expectation that nutritional stress increased as Euroamerican contact continued and bison availability decreased. However, closer examination of these means reveals unexpected results for the early variants. For example, Lower Loup phase medullary cavity width was expected to be smaller than that of the Central Plains tradition

Table 7. Results of archaeological variant contrasts for each variable.

Variable	Contrast ^a	DF	Contrast SS	F	PR > F
M	CPT vs LLP	1	0.57	0.17	0.6768
	LLP vs PWN	1	4.54	1.38	0.2414
	IMM vs CPT	1	8.11	2.46	0.1178
	IMM vs EC	1	9.49	2.88	0.0909
	EC vs PC	1	15.33	4.65	0.0319
	PC vs ARK	1	67.80	20.57	0.0001
	PRH vs HIS	1	36.53	11.09	0.0010
	PC vs CRW	1	32.59	9.89	0.0018
	ARK vs CRW	1	4.11	1.25	0.2650
T	CPT vs LLP	1	26.39	5.85	0.0162
	LLP vs PWN	1	0.72	0.16	0.6900
	IMM vs CPT	1	44.07	9.77	.0020
	IMM vs EC	1	20.73	4.60	0.0329
	EC vs PC	1	0.01	0.00	0.9590
	PC vs ARK	1	39.85	8.84	0.0032
	PRH vs HIS	1	13.34	2.96	0.0866
	PC vs CRW	1	2.22	0.49	0.4833
	ARK vs CRW	1	1.40	0.31	0.5785
C	CPT vs LLP	1	5.24	1.57	0.2108
	LLP vs PWN	1	1.64	0.49	0.4825
	IMM vs CPT	1	57.33	17.22	0.0001
	IMM vs EC	1	58.27	17.50	0.0001
	EC vs PC	1	16.19	4.87	0.0282
	PC vs ARK	1	3.69	1.11	0.2933
	PRH vs HIS	1	4.35	1.31	0.2541
	PC vs CRW	1	17.79	5.34	0.0215
	ARK vs CRW	1	10.30	3.09	0.0797

a. CPT, Central Plains tradition; LLP, Lower Loup phase; PWN, Pawnee; IMM, Initial Middle Missouri; EC, Extended Coalescent; PC, Postcontact Coalescent; ARK, Arikara; PRH, Protohistoric; HIS, Historic; CRW, Crow. Variable abbreviations are listed with Table 3.

Table 7 (continued).

Variable	Contrast	DF	Contrast SS	F	PR > F
NS	CPT vs LLP	1	0.00	0.10	0.7516
	LLP vs PWN	1	0.00	1.37	0.2421
	IMM vs CPT	1	0.02	7.00	0.0086
	IMM vs EC	1	0.04	11.22	0.0009
	EC vs PC	1	0.03	7.72	0.0058
	PC vs ARK	1	0.04	13.23	0.0003
	PRH vs HIS	1	0.03	8.23	0.0044
	PC vs CRW	1	0.04	11.27	0.0009
	ARK vs CRW	1	0.01	2.85	0.0927
CA	CPT vs LLP	1	22617.58	4.50	0.0348
	LLP vs PWN	1	46.45	0.01	0.9235
	IMM vs CPT	1	75535.83	15.03	0.0001
	IMM vs EC	1	56143.57	11.17	0.0009
	EC vs PC	1	5869.33	1.17	0.2808
	PC vs ARK	1	9478.58	1.89	0.1708
	PRH vs HIS	1	1932.37	0.38	0.5357
	PC vs CRW	1	2460.05	0.49	0.4848
	ARK vs CRW	1	7574.60	1.51	0.2207

a. CPT, Central Plains tradition; LLP, Lower Loup phase; PWN, Pawnee; IMM, Initial Middle Missouri; EC, Extended Coalescent; PC, Postcontact Coalescent; ARK, Arikara; PRH, Protohistoric; HIS, Historic; CRW, Crow. Variable abbreviations are listed with Table 3.

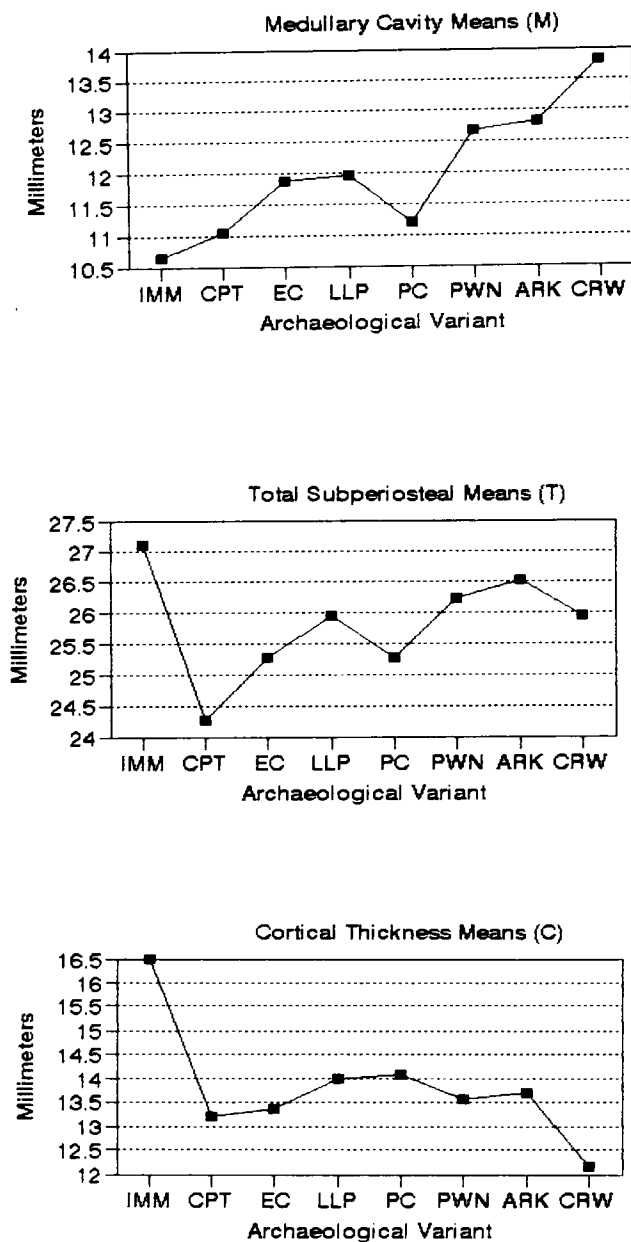


Figure 5. Means for medullary cavity width (M), total subperiosteal diameter (T), and cortical thickness (C) for Initial Middle Missouri (IMM), Central Plains tradition (CPT), Extended Coalescent (EC), Lower Loup phase (LLP), Postcontact Coalescent (PC), Pawnee (PWN), Arikara (ARK), and Crow (CRW).

due to improved climatic conditions and availability of bison. In addition, Initial Middle Missouri means for M were expected to be higher than those of the Extended Coalescent variant since lifeways of Initial Middle Missouri villagers are thought to have been similar to those of the Central Plains tradition villagers. Perhaps these earlier variants (i.e. Central Plains tradition and Initial Middle Missouri) were not experiencing as much nutritional stress as previously estimated.

Specific contrasts are useful for learning which variant differences are significant. Highly significant differences are evident when Postcontact Coalescent means are contrasted with those of the Arikara, or the Disorganized Coalescent, which supports the expectation that the earlier variant would exhibit less nutritional stress and thus smaller medullary cavities. In the same regard, when both Historic samples (Disorganized Coalescent-Arikara and Pawnee) were compared with Protohistoric samples (Lower Loup phase and Northern Plains Postcontact variant), the differences were highly significant. When the Postcontact and Crow samples are compared the mean differences are also highly significant which highlights the large medullary cavities of the Crow. Statistically significant differences were noted when the Extended Coalescent and Postcontact variants were contrasted illustrating the expected improvement in nutritional status in the Postcontact variant.

In general, means for subperiosteal diameter should reflect the changes on the endosteal surface (M) for the different variants. Figure 5 illustrates that means for T do not exactly follow this expectation. Initial Middle Missouri means for T are much higher

than expected given the low means for M. The Crow sample has a lower mean for T than expected due to its high medullary cavity mean.

As for medullary cavity width, a contrast between the Postcontact Coalescent and the Disorganized Coalescent variant (Arikara) reveals the mean differences for T are highly significant. Also highly significant, and predictably so, are the contrasted means of the Central Plains tradition and the Initial Middle Missouri variant. Additional contrasts demonstrate statistically significant means for the following variant comparisons: Central Plains tradition vs. Lower Loup phase and Initial Middle Missouri vs. the Extended Coalescent.

Cortical thicknesses (C) means for each variant are also illustrated in Figure 5. In general, if a variant demonstrates low means for medullary cavity width, cortical thickness means should be relatively high. (Since changes on the endosteal surface are more pronounced they are in effect responsible for the sample differences in cortical thickness.) The results of Duncan's test for C are remarkable because Initial Middle Missouri means are significantly different from the means for the other variants. This is not surprising given this variant's low medullary cavity means and high means for T; however, while Initial Middle Missouri villagers were not expected to demonstrate as much nutritional stress as the Central Plains tradition villagers, they were not expected to demonstrate higher cortical thickness, and better nutritional status, than all of the variants. Generally speaking, the rest of the cortical thickness means follow the expected pattern; however, greater differences from variant to variant were expected. Except for the Initial Middle Missouri and Crow samples, the means only show marginal variation. Means for both

Disorganized Coalescent samples (Arikara and Pawnee) are greater than expected given the high levels of nutritional stress due to inter-tribal conflict and Euroamerican contact.

Since the variants differences are small for cortical thickness, there are only a few significant contrasts. Not surprisingly, when Initial Middle Missouri means for C are contrasted separately with the Extended Coalescent variant and with the Central Plains tradition, the differences are highly significant. Statistically significant differences are found when the Extended Coalescent is contrasted with the Postcontact Coalescent, supporting the expectation that the Postcontact variant sample would have more cortical bone than the earlier variant due to improved conditions. Also statistically significant are the mean differences for C between the Postcontact variant and the Crow, which was also expected given the worsening situation for the Crow at that time.

Nordin's score indicates how much of the total diameter is bone cortex. Duncan's test shows that the Initial Middle Missouri and the Crow samples are significantly different than the other variant means. While the mean for Initial Middle Missouri is higher than expected, the Crow sample mean is low, as expected. Further expectations are met since both Disorganized Coalescent sample means are low and the Postcontact variant mean is high. The Central Plains tradition mean for NS is unexpectedly larger than both the Lower Loup phase and the Extended Coalescent variant.

Contrasts with Nordin's score produced many significant outcomes. All of the following contrasts for the variable NS are highly significant: Central Plains tradition vs. Initial Middle Missouri; Initial Middle Missouri vs. Extended Coalescent; Extended Coalescent vs. Postcontact Coalescent; Postcontact Coalescent vs. Arikara; Historic

(Arikara and Pawnee) vs. Protohistoric (Postcontact Coalescent and Lower Loup phase); and Postcontact Coalescent vs. Crow. Except for the contrasts involving the Initial Middle Missouri variant, the remaining all support the research expectations.

The final variable related to bone cortex is cortical area, which is an indicator of absolute bone mass. Duncan's test reveals again that the mean for CA for the Initial Middle Missouri variant is significantly different than the means for the other variants. Both Historic samples, Arikara and Pawnee, show higher means than expected while the Postcontact variant has a lower mean than expected. A highly significant contrast results between the means of the Initial Middle Missouri and Extended Coalescent samples and between the means of the Initial Middle Missouri variant and the Central Plains tradition. When the Central Plains and Lower Loup phase are contrasted, mean differences are statistically significant which supports the expectation that the Lower Loup phase will have a greater amount of cortical bone than the Central Plains tradition. Since cortical area assumes a cylindrical bone shape, and the femur does not maintain such a shape, sample means for this variable may not be completely reliable.

In summary, the most unforeseen results are the means demonstrated by the Initial Middle Missouri variant. This variant consistently displays means which are the complete opposite of what was expected and they are often extremely different than the means demonstrated by the other variants. Initial Middle Missouri villagers were expected to experience a significant amount of nutritional stress due to unfavorable climatic conditions and possible conflicts with neighboring villages. Instead, the means for this variant indicate the individuals were experiencing minimal nutritional stress. In addition, the

Central Plains tradition villagers do not exhibit the expected degree of nutritional stress, although they do demonstrate more nutritional stress than the Initial Middle Missouri villagers.

It is possible that the Initial Middle Missouri villagers were simply not experiencing the levels of nutritional stress they are thought to have endured. Perhaps evidence that the Initial Middle Missouri villagers lived in larger fortified villages and bison were more readily available in the area (compared with the Central Plains tradition) is more significant than previously believed. But this still does not explain the seemingly low level of nutritional stress experienced by the Central Plains tradition villagers, which is especially demonstrated by the means for medullary cavity width and Nordin's score.

Perhaps these prehistoric Plains villagers were maintaining high levels of activity while in pursuit of game and other food sources which in turn stimulated cortical bone growth counteracting any negative influences due to nutritional stress (Jantz, pers. comm.). If this is so, it is most likely attributable to the use of the femur, which is a weight bearing bone and high activity levels can influence its size and shape. Future research should consider using a non-weight bearing bone so the effects of activity can be avoided (Jantz, pers. comm.). It is possible that the unexpected results for both these variants is due simply to the fact that they are not representative of the population, but this seems unlikely considering the range of sites that comprise the samples.

Although mean differences are clear for each variable for each of the Central Plains variants, more significant differences were expected for these sites. Mean differences for the Central Plains variants were rarely significant when contrasted with

each other. Most of the significant differences are among the Northern Plains sites. Apart from the mean differences due to the Initial Middle Missouri sample, the most common significant contrasts among the variables are mean differences between the Extended and Postcontact Coalescent variant, between the Postcontact Coalescent variant and the Disorganized Coalescent (Arikara), and between the Postcontact variant and the Crow sample. Not surprisingly, these include the same three archaeological variants which Owsley (1985) found had significant mean differences for cortical thickness over time.

Studies of skeletal markers of nutritional activity may support the interpretation of these results. Studies of dental caries are often used to indicate the diet base of an archaeological group since caries are the result of reliance on carbohydrates. Dental caries are seldom found in groups that subsist on hunting, gathering, and fishing (Owsley and Bruwelheide, 1996). Eating foods high in carbohydrates, such as maize, leads to bacterial growth which in turn causes tooth enamel to decay. Meat, on the other hand, does not promote such bacterial growth and results in fewer caries (Owsley and Bruwelheide, 1996).

In one report, the presence of caries were noted in a Central Plains tradition sample indicating maize and other high carbohydrate foods were part of the subsistence base (Owsley and Jantz, 1989; Phenice, 1969 in Owsley and Bruwelheide, 1996). The Coalescent samples demonstrate fewer dental caries than the Central Plains Itskari phase sample (Owsley and Jantz, 1989; Phenice, 1969 in Owsley and Bruwelheide, 1996). This supports the expectation that groups living during the more recent variants were eating a more balanced diet when bison meat was more available. The Disorganized Coalescent

variant demonstrates the fewest caries indicating the heaviest reliance on meat (Owsley and Jantz, 1989; Phenice, 1969 in Owsley and Bruwelheide, 1996). This may in part explain the loss of cortical bone for this sample since heavy reliance on meat may have resulted in loss of calcium due to a high intake of phosphorous.

Research dealing with other indicators of nutritional stress in Plains populations such as enamel hypoplasia have not been as successful in finding useful results. Dental enamel hypoplasia, or bands or pits in dentition, results from malnutrition and disease that occur during childhood and has been used to estimate environmental stress. Use of these enamel defects as indicators of childhood stress is preferred to Harris lines, which can be obliterated by bone remodeling in adulthood (Owsley and Bruwelheide, 1996).

One study that investigates dental defects in Plains populations by Toth and Peterson (1992) did not find highly significant differences in dental disease between prehistoric and historic samples from Nebraska. They report there were only a small percentage of people with enamel hypoplasia in both the prehistoric and the historic group, however incidence of enamel hypoplasia was very rare in the historic sample. This would indicate better child health during the historic period. However, Toth and Peterson (1992) do point out that the effects of an acute disease such as smallpox would not have caused enamel hypoplasia. Furthermore, the authors found a higher incidence of anterior tooth wear during the historic period which they argue would have concealed any indication of enamel hypoplasia. Based on this evidence, they refrain from drawing conclusions about child health during the historic period.

Another study of enamel hypoplasia among Plains Indians reveals that samples dating to the Extended and Postcontact Coalescent demonstrate a higher incidence of hypoplastic lines than a Disorganized Coalescent sample of Arikara from the Leavenworth (39CO9) site (Cashion, 1987 in Owsley and Bruwelheide, 1996). This would indicate an improvement in health over time. These results are questioned based on the deteriorating conditions at sites such as Leavenworth due to disease from Euroamerican contact and inter-tribal conflict (Owsley and Bruwelheide, 1996).

Cashion (1987 in Owsley and Bruwelheide, 1996) did however find a high incidence of enamel hypoplasia at the Linwood (25BU1) site in Nebraska. The conflicting results between the two Disorganized Coalescent samples prompted a similar explanation to the one offered by Toth and Peterson (1992). Again, a difference in dental wear resulting in a lower enamel height among the Arikara is attributed to the fewer amount of hypoplastic lines detected among the Arikara (Cashion, 1987 in Owsley and Bruwelheide, 1996).

These studies illuminate the difficulty in finding adequate markers of physiological and environmental stress. Cortical thickness has proven to be a useful indicator of nutritional stress in previous studies and in this one.

VI. CONCLUSIONS

This investigation was designed to illustrate the relationship of nutritional status and cortical bone thickness for archaeological samples of Central and Northern Plains Indians. From a general standpoint, the results of this study were favorable. The general linear models statistic results show highly significant variant differences for all the variables (except maximum length).

The expanded Northern Plains samples were expected to follow the pattern previously demonstrated by Owsley (1985). An increase in cortical bone was expected between the Extended and Postcontact Coalescent variants due to an amelioration of unfavorable climatic influences and the introduction of the horse. This was expected to be followed by a decline in cortical thickness during the Disorganized Coalescent variant due to an increased incidence of disease and inter-tribal conflict. Finally, the equestrian nomad sample of Crow was expected to demonstrate high amounts of nutritional stress through small cortical thickness values. It can be concluded that these expectations were all met successfully.

Unfortunately, results for the Central Plains variants were not as satisfying. The Central Plains tradition villagers were expected to demonstrate nutritional stress due primarily to unfavorable climatic conditions. An increase in bison and a decrease of dry weather conditions during the protohistoric period was expected to result in less nutritional stress and higher cortical thickness values for the Lower Loup phase sample.

Finally, as disease and inter-tribal conflict were on the rise and food sources were diminishing during the Disorganized Coalescent, the Pawnee were expected to show low cortical thickness values due to poor nutritional status. Expected mean differences were usually observed between the Lower Loup phase and the Disorganized Coalescent variant, they simply were not significant.

A greater problem is evident for the Central Plains tradition variant for which the means do not indicate the expected level of nutritional stress. Similarly, the Initial Middle Missouri variant also consistently demonstrated unexpected variable means. One possible explanation for these unexpected results is that while in earnest pursuit of available food sources, both Central Plains tradition and Initial Middle Missouri villagers stimulated cortical bone growth by maintaining high levels of activity. Before any conclusions can be reached with certainty concerning these two variants, additional research is needed.

Hopefully, this study will prove a worthwhile contribution to the investigation of cortical thickness among Indians of the Great Plains.

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VITA

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