PALEOPATHOLOGIST AS DETECTIVE: DISEASE AND DEATH IN PREHISTORY

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The work of the paleopathologist is similar to that of a detective. Just as the detective must reconstruct a crime by sifting through the evidence for clues that reveal a pattern, the paleopathologist (scientist who studies disease in ancient populations) must analyze the bones and artifacts of populations long dead in order to understand their patterns of disease and death. For the detective, the major objective is to determine that a crime has been committed and to uncover the perpetrators; for the paleopathologist, it is to analyze prehistoric skeletal remains to understand how a population lived and died.

In the past two hundred years, paleopathologists have discovered a variety of human ailments in ancient populations. Trauma, amputation, infectious conditions such as syphilis and tuberculosis, congenital defects, rickets (vitamin D deficiency), arthritis, malignant tumors, and even poisoning from toxic substances have been found in prehistoric populations (for a review of paleopathology see Brothwell and Sandison 1967; Ortner and Putschar; Steinbock 1976; Wells 1964). These discoveries have helped us trace the evolution of those diseases to modern times, through the examination of their history and geography. But the contribution of paleopathology goes beyond space and time and single diseases; it can help to reconstruct the lifeway of a society and its adjustment to its environment.

Disease and death are not random events; they form discernible patterns. As Calvin Wells notes:

> The pattern of disease or injuries that affect any group of people is never a matter of chance. It is invariably the expression of stresses and strains to which they were exposed, a response to everything in their environment and behavior. It reflects their genetic inheritance (which is their internal environment), the climate in which they lived, the soil that gave them sustenance and the animals or plants that shared their homeland. It is influenced by their daily occupation, their habits of diet, their

choice of dwelling and clothes, their social structure, even their folklore and mythology [1964:17].

The objective of this study (with apologies to Sir Arthur Conan Doyle) is to use the analogy of detective work to illustrate the methods and techniques of paleopathology. The paleopathologist uses deductive and inductive means to diagnose and understand disease patterns.

Artifacts such as splints, surgical instruments, and figurines showing individuals afflicted with lesions aid in defining patterns of pathology of a population. However, the best evidence of disease is the biological remains: mummified tissue and the skeleton itself. The paleopathologist, using methods of deduction and induction, can usually determine the causes of skeletal abnormality. By gross observation of the skeleton, and radiographic, chemical, and histological analysis, pathology can be diagnosed. Having determined the cause of the pathology, the paleopathologist, using other levels of deduction and induction, can then analyze the ecological and cultural factors which may contribute to the disease process.

The systematic analysis of disease and death in prehistory is enhanced by the use of a model (Huss-Ashmore et al. 1982) which incorporates biological and cultural variables affecting survival (Figure 1). The environment is the source of the necessary resources; deficiency in any essential resource can constrain the development of the population in some way. For example, if the amount of quality protein is limited, there are two possible outcomes: the population size may be restricted and everyone may receive their necessary requirements, or population may grow beyond this limit, creating deficiencies for some members of the group. If that happens, social and economic factors are likely to determine who has access to the available protein and which segments of the population will experience deficiencies.

The environment is also the source of other stressors which affect the individuals' or populations' ability to adjust (or adapt) to their environment. Stressors can be any physical, chemical, biological, physiological or social factors which affect adaptation (Audy and Dunn 1974:329). Trauma (physical injuries), toxins (chemical), pollutants (chemical), and pathogens (biological) are examples of insults which can hamper the survival ability of the individual or group.

Human populations exist within a cultural system that acts to buffer them from environmental constraints and stressors. The cultural system includes technology (the means of extracting energy and other resources from the environment), the social system (the way in which a group organizes itself to maintain its technology and to reproduce itself), and ideology (ideas, attitudes and beliefs). In most instances, a group's culture effectively filters harsh stressors originating in the environment. Material aspects of culture such as shelter and food (products of the technology), social support engendered by kin and friends (products of the social system), and the construction of a world view (product of the ideological system) are important cultural factors which attenuate the rigors of any environment.

However, while the cultural system provides for most of our needs and protects us from many of our fears, it can in some instances create stressors which actually decrease the potential for survival. The shift to an agricultural subsistence base only 10,000 years ago significantly altered the pattern of disease in human population through technological changes in the environment and changes in the social system.

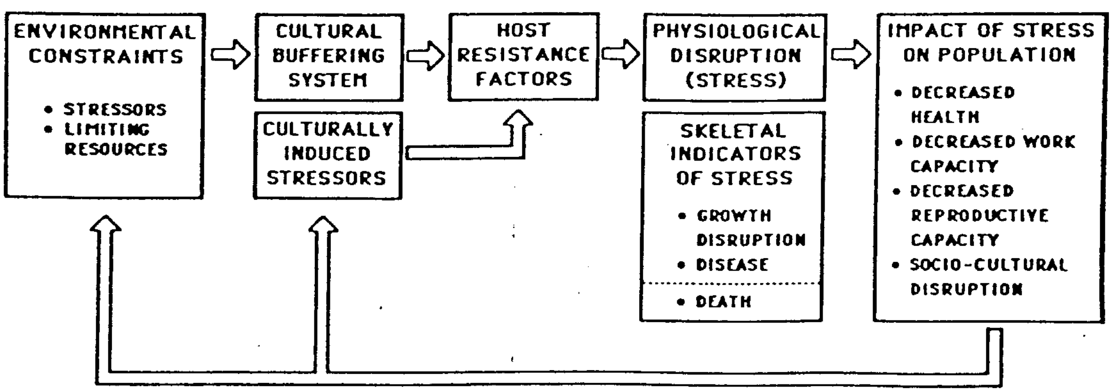


Figure 1. General Model for analysis of skeletal remains.
(after Huss-Ashmore et al, 1982)

Agriculture technology often changes the environment significantly. The cultivation of the soil itself exposes the population to novel insects such as scrub typhus. Since care of agricultural fields forces the population to become sedentary, it creates problems with waste disposal. Gatherer-hunters move frequently enough that human waste does not accumulate in their camps, but sedentary populations rapidly accumulate waste and it often contaminates their drinking water. Because of the close interpersonal contact that characterizes agricultural groups and the increase in population size and density, the exposure to infectious disease is likely to increase (Armelagos and Dewey 1970; Armelagos and McArdle 1975; Armelagos et al. 1990; Boyden 1970; Cockburn 1967a, 1967b, 1971; Fenner 1970; Haldane 1949; Polgar 1964). Thus with the development of agricultural technology, infectious diseases became a major force in our evolution (Haldane 1949).

Even the belief system can create potential problems. While myths may comfort a group by explaining the unknown, they can also instill fear, causing psychological and physical stress. And the system of belief may taboo certain food items, leading to nutritional deficiency for some members of the society.

Stressors, whether they arise from the environment and are not buffered by the culture or have their source in the culture system, ultimately have some effect on the individual or population (host). The impact of the stressor is variable. The strength and duration of the stressor and the health of the individual are obviously important. A weakened individual may not be able to resist a fairly minor insult for a short period of time, while a healthy individual may be able to resist a major insult for a relatively longer period. In this context, disease is defined as a decrease in adaptation resulting from insults, while health is defined as the ability to rally from insults (Audy and Dunn 1974).

For the paleopathologist, analysis of disease at the population level is extremely important. While the initial diagnosis is made on an individual, the interpretation of most biocultural interactions requires an analysis of insults within the population.

The attempt of the host to resist the stressor is accompanied by physiological disruption (stress) (Goodman et al. 1988). In contrast to modern physicians, paleopathologists can observe physiological disruption only in bones and, if mummification has occurred, in the tissue that adheres to them. In living populations, physiological disruption can also be measured in soft tissue and body fluids such as blood and urine, and physicians can assess the health of patients by asking them how they feel or by objectively evaluating how well they function mentally and physically. (While there are obvious advantages for physicians working with living populations, paleopathologists hardly ever hear complaints from their "patients.")

Since the paleopathologists usually have only skeletal remains from which to make their diagnoses, only illnesses which leave their mark on bones will be discovered. The response that bone can make to stress is limited: the body can manufacture new bone cells (deposition) and it can remove bone cells (resorption) or do both. However, despite the limited range of response, insults often leave a "signature" on bone that is so distinctive it can be used in diagnosis. For example, syphilis (Baker and Armelagos 1988; Hackett 1963) and tuberculosis (Buikstra 1981; Clark et al. 1985) leave unique lesions in response to the pathogen. Skeletal response to tuberculosis is often found in the spine, in which there is a collapse of body with no involvement of the bone which surrounds the spinal canal.

There are also infectious diseases which cause non-specific changes in bone. Pathogens such as staphylococcus can cause changes in the outer covering of bone (the periosteum). Periostitis (the periosteal reaction to inflammation) can be important in assessing the health of the population since it indicates that there is a general and systemic infection present. There are, however, obviously important infectious conditions which leave no skeletal evidence. Viral diseases, for example, do not appear to cause any skeletal changes.

Nutritional deficiencies provide paleopathologists with some of our most difficult challenges. It has been possible to detect skeletal evidence of rickets (vitamin D deficiency) and scurvy (vitamin C deficiency) in ancient populations for 20 years. However, only recently have we succeeded in attempts at systematic analysis of other nutritional deficiencies that are more difficult to interpret. As late as 1975 Calvin Wells wrote, "No indubitable examples of Kwashiorkor are known from ancient burial grounds and it is unlikely that any will be recognized unless some wholly unexpected method of identification can be devised" (1975:758). Wells believed that new technological innovations would be necessary to observe the more complex nutritional deficiencies. While the development of new methods of chemical analysis has greatly aided our research, it has been the systematic application of existing technology that has been the key to unraveling the dietary puzzle.

The case studies of two widely divergent archaeological populations which follow make it clear that existing methods can uncover nutritional, infectious, and other diseases in the burial population. Drawing on multiple indicators of nutritional deficiency which provide information on dietary status (Goodman et al. 1984; Huss-Ashmore et al. 1982; Larsen 1987; Martin et al. 1985). We can begin to investigate the patterns of pathology that will allow us to understand health problems faced by people in the past.

THE NUBIAN CASE

Our detective story focuses on the Wadi Halfa region of Sudanese Nubia (Figure 2), where paleopathological techniques enabled a research team to draw conclusions about Nubian cultural and social patterns. The Nubian populations span a 1,500 year period from the birth of Christ. The analysis of the Nubian populations is based on excellent archeological and skeletal remains recovered from this area. The analysis reported in this study resulted from the excavation in 1963 of over 800 burials as part of the UNESCO Project to Save the Monuments of Nubia. The Nubian area represents one of the most intensively studied archeological populations in the world. Over 366 major expeditions have excavated more than 1,000 sites in the past 75 years (Adams 1977). The history of the populations discussed here spans 1,500 years, including the Meroitic (A.D. 0 - 350), X-Group (A.D. 350 - 550), and Christian (A.D. 550-1500) periods. The Nubians during these years were engaged in intensive agriculture. The Meroitic period represents the highest development of Sudanese culture to that time. During this period the Kingdom of Kush gained control of large areas of Northwest Africa. The X-Group period can be characterized by local control of smaller areas following the decline of the Meroitic Empire and prior to the reunification of Nubia with the conversion to Christianity.

The Nubian remains are very well preserved because of the arid conditions and their burial in sand. Although there is no evidence of purposeful mummification, natural factors led to the desiccation of the tissue before it could be destroyed by bacteria and insects. The excellent preservation enhanced our analysis. For instance, external sex organs were preserved in 20% of the population, making the assessing of sex a much easier task.

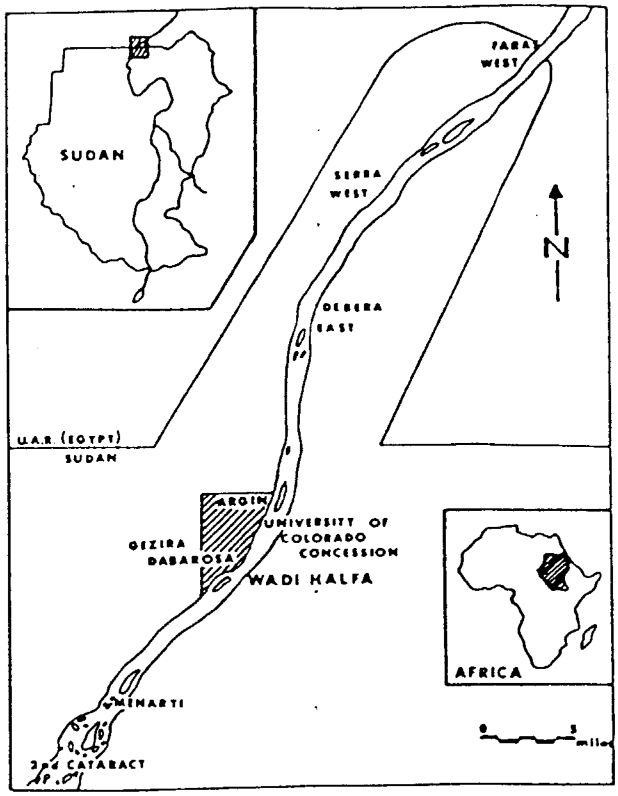


Figure 2. Map of Wadi Halfa
(after Armelagos 1968:2)

The preservation of hair and skin provides information about hair styling and personal adornment. There is evidence of tattooing and scarification; males wore beards, and females pierced their ears. Forty percent of those individuals with hair preserved showed evidence of infestation by head lice (*Pediculus capitus*) who met the same fate as their mummified hosts.

Even a single pathological condition reveals a great deal of biological and cultural information. For example, a ten-year-old child with severe hydrocephaly was found in the Nubia X-Group cemetery. By studying this burial we were able to draw conclusions about the treatment of handicapped individuals in Nubian society. Hydrocephaly is a congenital defect that occurs when an accumulation of fluid in the brain results in an increase in the cerebral mass. The child's cranial capacity measured 1,825 cubic centimeters, 29% greater than the average adult cranium (Schawelson and Armelagos 1984).

The impact of hydrocephaly in the living can be assessed by observing and testing their mental and physical ability. In prehistory, locomotor ability is evaluated by examining the development of the long bones. In this case the child's femur (thigh bone) is 10% shorter and the tibia (lower leg bone) is 18% shorter than age-matched controls. The humerus (upper arm bone) is 9% shorter than the control sample. These lengths are comparable to those found in seven- and nine-year-old children in the group cemetery.

The most dramatic differences from normal skeletal development are observed in the diameters of the hydrocephalic child's long bones. The anterior-posterior diameter of the femur is 61% smaller and the humerus 44% smaller than age-matched normal individuals; in fact, the diameters are equivalent to those found in two-year-old children. Since bone diameters respond most directly to muscle use, these dramatically underdeveloped long bones suggest that the child was a quadriplegic.

In twentieth century hydrocephalics, there is usually greater impact on the muscular development of the lower extremities, since the expansion of the lateral ventricle of the brain initially stretches the nerve fibers which control the lower extremities. The growth of the cranium and the failure of long bone development suggests in this case that the hydrocephaly began at or near birth.

In addition to the locomotor changes, the child in point had a dental malocclusion, with the upper and lower incisors protruding at a 45 degree angle. This malocclusion is consistent with habitual thrusting of the tongue against the front teeth. The anterior teeth also were heavily encrusted with tartar formation, indicating the child was fed a diet of mushy cereal and had difficulty in controlling saliva.

The hydrocephalic child clearly would have required extensive care. The fact that he or she lived into her tenth year suggests that members of X-Group society were willing and able to care for an individual with severe disability.

Even the location and the rate of trauma, as indicated by healed and non-healed fractures, can reveal information about social relations. Fracture of the bones of the forearm (the radius and ulna) at the midshaft usually results when one extends the arm to parry a blow. Fractures at the wrist usually occur when an individual falls and extends an arm to break the fall. Thus the frequency of "parry" fractures can be used as an index of strife in society, while fractures of the wrist serve as an index of "klutziness."

When compared with Anglo-Saxons, the Nubians have a lower frequency of fracture of the wrist; this is probably more of a reflection of the sandy Nubian landscape and the wearing of thin-soled sandals than to any differences in inherent agility.

In the Christian period, there is an increase in the frequency of postcranial trauma from 5% in previous periods to over 11%, with fractures now found more frequently among the women. Many of these injuries to the women are multiple fractures of the type that would result from a beating. This would suggest that the status of women was declining in this Christian site (Armelagos 1969).

Did the Ancient Nubians Anticipate Modern Medicine?

The paleopathologist's detective work can also be illustrated by the serendipitous discovery that the broad spectrum antibiotic tetracycline was used by the Nubians at least 1,400 years ago. Debra Martin, then an anthropology graduate student at the University of Massachusetts, was spending a few days at the calcified tissue laboratory of Henry Ford Hospital in Detroit, Michigan, refining techniques for making thin sections from archeological bone. The technique for preparing a thin section of bone requires hand grinding to a thickness of one hundred microns (a little thicker than the paper you are reading).

In order to determine the correct and uniform thickness, the thin bone sections are frequently examined under a standard light-transmitting microscope. While preparing to examine a thin section, Martin discovered that the light-transmitting microscope was in use. Another researcher in the laboratory offered her a microscope used to measure fluorescence in bone. To Martin's astonishment, the archeological bone from the X-Group period (A.D. 350-550) showed the unique yellow-green fluorescence characteristic of tetracyclines when exposed to ultraviolet light at the 490 nanometer wave length.[1] Her discovery of tetracycline in a population that lived from 1,400 to 1,600 years ago was as surprising as if someone unwrapping a mummy found a pair of Ray-Ban sunglasses strapped to its head.

There are several questions which must be answered if we are to believe that tetracyclines were being used by the ancient Nubians: Is it really tetracycline? Is there evidence that the tetracycline was ingested prior to death? Or is it the result of post mortem contamination? And if it was ingested, what was the source of the antibiotic?

Research clearly suggests that the substance is a form of tetracycline (Basset et al. 1981). Its yellow-green fluorescence occurs at the expected wave length and the color is characteristic of tetracyclines. James Booth, one of the scientists who originally worked on the commercial application of tetracycline, has been able to extract the antibiotic from archeological bone from Nubia, and found that it still possesses its ability to kill bacteria (Booth, personal communication).

Was the tetracycline a contaminant of the decay process? It has been argued (Piepenbrink 1986; Piepenbrink et al. 1983) that most tetracycline labeling is due to post mortem changes that occur when bone deteriorates and is invaded by bacteria and fungus that produce tetracycline. When this occurs there is evidence of destruction of the bone and often a diffuse labeling of bone surfaces and especially undermineralized osteons. Margaret Keith and George Armelagos (1988) have shown that in the Nubian archeological bone the tetracycline labels fully mineralized osteons which are adjacent to unlabeled, unmineralized osteons. In addition, there is no evidence of deterioration of bone or any other indication that tetracycline is the result of post mortem changes.

Tetracycline is manufactured by a streptomycetes, a mold-like bacteria. The bacteria, which is prevalent in Nubian soil, would have come into contact with the stored millet, barley, and sorghum that were major staples of the Nubian diet. The contaminated grain could have been eaten as bread, but we suspect that it was brewed as beer.[2] Whatever the source of tetracyclines, the ancient Nubians were apparently receiving therapeutic doses of the antibiotic. The skeletal population, for instance, shows and unexpectedly low rate of infectious lesions of the bone.

If the Nubians enjoyed some "natural protection" against infectious disease, was their overall health good? Our evidence tells us not. The study of a number of skeletal lesions indicates they suffered from serious nutritional problems. As early as 1968, Paul Mahler in a study of long-bone length suggested that the Nubian children dentally between the ages of two and six had shorter than expected long bones (Mahler 1968; see also Armelagos et al. 1972). At the time, it was suggested that this might represent growth retardation associated with weaning. However, the small sample sizes and the fact that we were dealing with cross-sectional data made the results ambiguous.

Another clue to suggest that nutritional deficiencies exist was the occurrence of a skeletal pathology called porotic hyperostosis. Porotic hyperostosis is defined as an expansion of bone (hyperostosis) in which there is also a very porous appearance to the external covering. The lesion usually occurs on the thin bones of the skull (the roof of the orbits, the frontal bone and the parietals), and is usually a response to anemia. The middle of these thin bones (the diploe) is an area where red blood cells are manufactured. In response to an anemia, the red blood cell production increases, causing the diploe to expand. This response results in a thinning of the outer table, exposing trabecular bone, which gives the porous appearance.

Since there are many conditions which cause anemia, it is necessary to determine the most likely cause. Hereditary hemolytic anemias such as thalassemia and sickle cell anemia, hereditary nonsperocytic anemias such as glucose 6-phosphate dehydrogenase deficiency, and even nutritional anemia such as iron-deficiency anemia, can cause porotic hyperostosis. There are two factors which suggest that iron deficiency anemia is the most likely cause of porotic hyperostosis in the Nubian populations. If it were a hereditary anemia, we would expect to find porotic hyperostosis involving many of the cranial bones and there would likely be postcranial changes. In the Nubian population, 21% of the skeletons showed evidence of porotic hyperostosis which was restricted to the upper portion of the orbits. Additionally, the highest frequency (32%) is in children under the age of ten. Young adult females are also affected at a high frequency.

An analysis of the microstructure of Nubian bone gave us our best evidence that Nubians were suffering from nutritional deficiency. The microscopic structure of the Nubian bones has been studied extensively in our analysis of age-related bone loss. Osteoporosis occurs frequently in older women in modern populations; the first report of its occurrence in prehistoric populations was made by Dewey et al. in 1969. Their analysis of femur cross sections showed that the Nubians began to lose bone at about age 30 (a little earlier than modern populations), and to continue losing bone at a slow and steady rate.

In modern populations there is an acceleration of bone loss after menopause and, since women are smaller than men and have less skeletal mass to begin with, they suffer from pathological fractures more often than men. While the rate of bone loss in Nubian females was similar to that of their modern counterparts, the ancient skeletons show no evidence of pathological fracture. Since most of the Nubians had died by their sixtieth year, their bone loss had not progressed long enough to create the conditions for a fracture rate comparable to that of modern American women. In the United States, 75% of the population live past their sixtieth year, 29% past their eightieth year, and 6% past their ninetieth year.

It was during the study of osteoporosis that Dr. Debra Martin realized that females in their peak reproductive period show premature bone loss (Martin and Armelagos 1979; Martin 1983). In her analysis of the histological change, Martin was able to show the process involved in the "great bone robbery." By studying the frequency of resorption spaces and forming osteons in the periosteal region and the middle and endosteal surfaces, she was able to show the mechanism of bone loss. She was able to demonstrate that females between 20 and 29 years of age had a higher frequency of resorption spaces and forming osteons. Furthermore, the Nubian females showed evidence of bone being resorbed (removed) from the endosteal (inner surface surrounding the medullary cavity), and while bone cells were being formed on the outer periosteal surface those cells (osteons) were not being mineralized. The calcium that was being resorbed from the bone of these women is not being recycled to mineralize the osteons that are being formed. Instead, the calcium is being passed on to children during lactation.

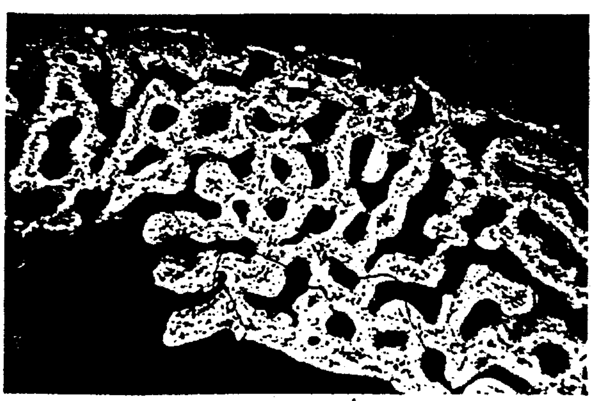
While the Nubian children may have been receiving their mothers' calcium during lactation, their skeletal remains also show evidence of impaired calcium metabolism. Long-bone growth seems to have been slow when compared with modern standards, and microscopic analyses of femur cross-sections show evidence of bone loss in children as young as two years of age (Figure 3). The resorption of bone may be an attempt by the skeletal system to maintain long-bone length at the expense of long-bone width. The complex of pathological conditions and evidence of nutritional deficiencies found in the children suggest that they are suffering from Kwashiorkor. The age distribution of the iron deficiency, the pattern of long-bone growth, the failure to develop cortical bone (and evidence of extensive resorption), and the pattern of mortality are consistent with kwashiorkor.

Interestingly, Hummert and Van Gerven (1982) have confirmed this pattern in another Christian Nubian population from the island of Kulubanarti. They also show that the bone loss results in bones that are biomechanically stronger than bones showing less loss. However, these stronger bones will lack the calcium reserves necessary to meet other episodes of nutritional deficiency.

The nutritional problems of ancient Nubian women and children can be related to a number of factors: the pattern of birth spacing, the breast-feeding practices, parasites, and diet. The reliance on cereal grains (barley, millet, and sorghum) which are poor sources of iron and calcium was undoubtedly a major contributing factor to the dietary deficiency. The intensification of agriculture, creating dependence on cereal grains, is the ultimate factor.

The Detective's Conclusion

In summary, the determination of Nubian nutritional deficiency involved a number of lines of evidence. The paleopathologist working from the macroscopic level (seeing deviation in growth patterns and evidence of iron deficiency anemia) is able to evaluate these changes by understanding the process at the histological level. Furthermore, by examining various age groups (young children, and women at the age of childbearing) we are able to link segments of the population that are at risk. Finally, this pattern of pathology can be traced to a cultural practice (intensification of agriculture) which increased the use of cereal grains which are deficient in calcium and iron.



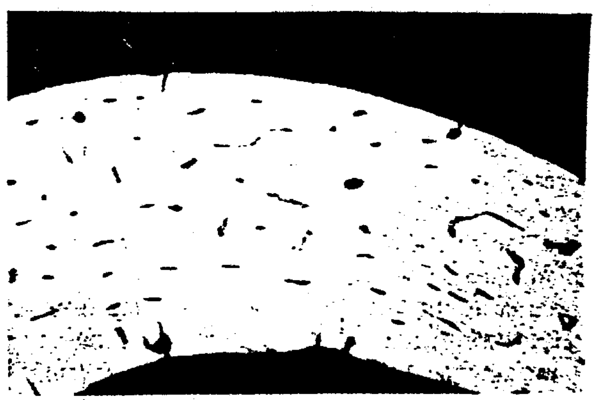


Figure 3. The osteoporotic, poorly mineralized cortex on a femur of a Nubian subadult (aged 2-6 at death) documents nutritional deficiency. A normal, well-maintained cortex is shown on the right.
(Microradiographs, magnified 50x, courtesy of Debra Martin.)

What makes the discovery of the decline in health so interesting is that it flies in the face of traditional interpretations, which argue that the shift to agriculture resulted in improved health and nutrition. After all, how else could one explain the rapid increase in population following the development of agriculture? However, as often happens, common wisdom may be misleading, for the skeletal evidence clearly shows that the development and intensification of agriculture increased the potential for infectious disease. Mark N. Cohen (1977) suggests that the decline in health may have preceded the development of agriculture. He argues that nutritional stress may have occurred as a result of an increase in population pressure which precedes the intensification of agriculture. In fact, Cohen would argue that it was an increase in population pressure which caused the increase in nutritional stress that may have forced the populations to intensify their production of agricultural products.

THE NEXT CASE: THE DICKSON MOUNDS

The Dickson Mounds offer an unusual opportunity to test the hypothesis that agriculture can have a deleterious impact on health. First of all, the prehistoric population buried in the mound was excavated by Alan Harn very carefully and the archeological context noted in detail (Harn 1971, 1980). Second, the archaeological evidence shows that the society had experienced a rapid transformation to intensive maize agriculture, and the burial population includes individuals from both the pre-intensive maize agriculture (Late Woodland and Mississippian Acculturated Late Woodland) periods and the intensive agriculturalist (Middle Mississippian) society. Third, the analysis of dental traits shows that the Dickson Mound population remained genetically stable across those time periods. Fourth, the research design involved a "double blind" approach in which the paleopathologist was not aware whether the skeleton under study was associated with pre-agriculturalist or intensive agriculturalist period.

The shift from a Late Woodland to a Mississippian lifestyle took 250 years. The Late Woodland occupation at Dickson Mounds is dated from A.D. 950-1100. It has been described as a gathering-hunting group with a population of between 75 to 125 individuals occupying seasonal campsites. During the later phases of the Woodland period, the Dickson population came under the influence of Middle Mississippian groups at Cahokia (Fowler

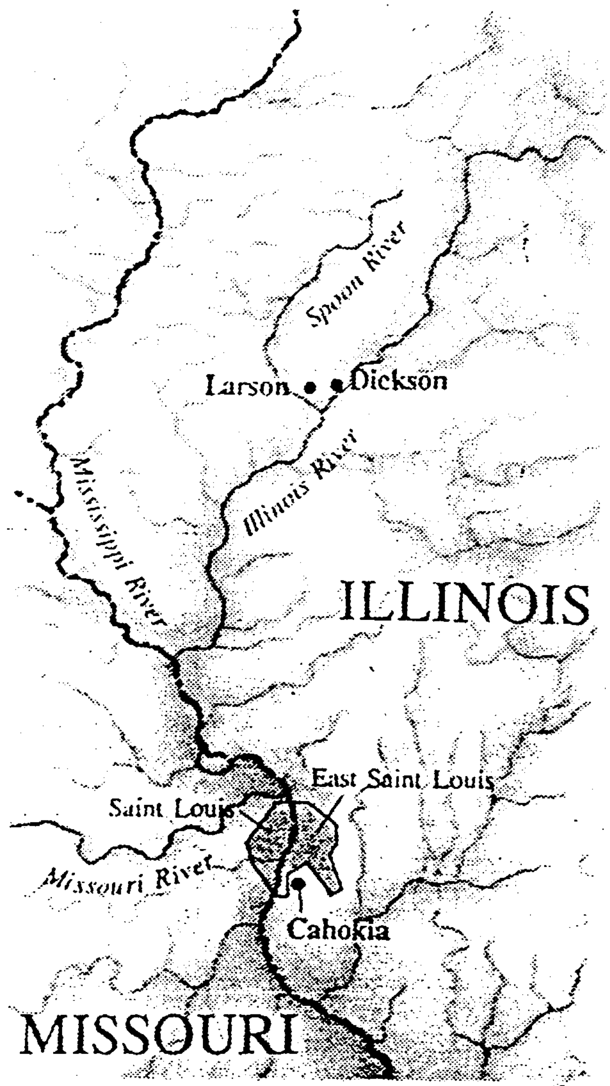


Figure 4. Dickson Mounds, in the Illinois River valley, is 180 km north of the major Mississippian site of Cahokia.
(Map by Joe LeMonnier, courtesy of *Natural History*.)

1978), which is 180 km to the south (Figure 4). The site of Cahokia is enormous: six square miles in size, it included 120 mounds and was occupied by as many as 30,000 individuals. By the end of the Late Woodland period the influence of the Middle Mississippian culture was so pervasive in the region and the transformation of society so significant that the period is referred to as the Mississippian Acculturated Late Woodland Period (A.D. 1100-1200).

The zenith of this cultural development was the Middle Mississippian period, which occurred from A.D. 1200-1300. During this period at Dickson there were hamlets which were surrounded by support camps, work stations associated with local

Table I. Frequency of Infectious Lesions (Periostitis and Osteomyelitis) and Porotic Hyperostosis

Dickson population	N	Postcranial infectious lesions N	%	Porotic hyperostosis N	%	Porotic hyperostosos and infections lesions N	%
Late Woodland	44	9	20.5	6	13.6	3	6.5
Mississipian/Acculturated Late Woodland	93	45	48.4	29	31.2	20	21.5
Middle Mississipian	101	74	73.3	52	51.5	41	40.6
Total	238	128	53.8	87	36.5	64	26.9

(Modified from Lallo et al. 1977:479).

ceremonial centers, and sites where resources were extracted (Harn 1978). It has been estimated that 600 to 1,170 individuals lived in the 234 habitation structures.

Originally, there was a suggestion that the changes at Dickson Mounds may have been the result of a shift in population. That is, agriculture had been brought in by a new population, probably migrating from Cahokia. In 1974 Janice Cohen calculated the genetic distance of the populations from the three periods at Dickson Mounds from a Mississippian population at Cahokia described by Fowler in 1969. Cohen's analysis of dental traits determined to have a high degree of heritability showed no significant difference between the Late Woodland, Mississippian Acculturated Late Woodland and Middle Mississippian populations at Dickson. Comparison of the Dickson population with that from Mound 72 at Cahokia indicated significant differences in shoveling of the canines and incisors, median ridges, gingival borders, Carabelli's cusp, and molar groove patterns. In addition, the Mahalanobis D-square value for Cahokia (4.01) was ten times greater than the interval difference at Dickson (0.41). This analysis suggests that we are dealing with the same population through time at Dickson and that population replacement from Cahokia was not evident.

During the course of the transformation from gathering-hunting to agriculture during the Middle Mississippian period, three trends affecting the adaptation developed and reached their pinnacle: maize agriculture was intensified; population size, population density, and sedentarism increased; and trade was extended and intensified.

Concurrently, the health of the Dickson Mound population deteriorated. During this period there was a reduction in long-bone lengths, an increase in iron deficiency anemia (porotic hyperostosis) from 13% to 51%, an increase in infectious disease involving the tibia (periosteal reaction) from 26% to 84% (Table 1), an increase in frequency of degenerative lesions of the spine from 40% to 66%, an increase in traumatic lesions from 14% to 20%, an increase in enamel hypoplasias, and a decrease in life expectancy at every age interval.

There are a number of very interesting features in this change in health. The fourfold increase in iron deficiency anemia (as measured by porotic hyperostosis) and threefold increase in infectious lesions (measured by periosteal reaction) from Late Woodland to Middle Mississippian period is quite remarkable. In addition, during the Middle Mississippian period, the number of individuals with both iron deficiency anemia and infectious lesions increases, and those individuals with both conditions suffer from a more serious manifestation of each condition. This synergistic relationship between nutrition and infection has been reported for many contemporary Third World populations suffering from nutritional deficiencies and infections.

The impact of iron deficiency anemia and infection can be determined by constructing life tables for children who have died within their first ten years. If we compare estimated life expectancy for those without porotic hyperostosis or infection with those with each condition, we can see that the individual with porotic hyperostosis has between a two-month and six-month decrease in life expectancy during the first ten years (Figure 5). Infectious lesions have an even greater impact on mortality. Those born with infections have a life expectancy of less than a year, while those with no lesions have a life expectancy of over two years.

The examination of long-bone growth also reflects the impact of changes in subsistence. Children between five and ten years old have significantly longer and wider femurs and tibias in the pre-Mississippian population than Mississippian children of the same age. These differences may be related to decreased growth velocity prior to age five. However, there is some evidence from the adult burials that the Middle Mississippian growth rates may have been able to catch up after age ten, since there are only slight differences in the long bones of adults in the two populations.

The recovery or catch-up growth reported in many populations often obscures the disruption that occurs earlier in life. There is, however, one stress indicator that leaves an indelible "memory" of earlier metabolic events. Enamel hypoplasia, a deficiency in enamel thickness, occurs when an individual suffers a systemic physiological disruption during the time when the enamel is formed. A variety of stressors, including malnutrition and infection, can affect enamel formation. Since we know the timing of enamel formation is stable, we can determine the age at which the lesion occurred.

At Dickson Mounds, adults with permanent dentition (which forms between birth and their seventh year) show an increase of hypoplasias from 55% in the pre-Mississippians to 80% in the Mississippian population. When we compare the

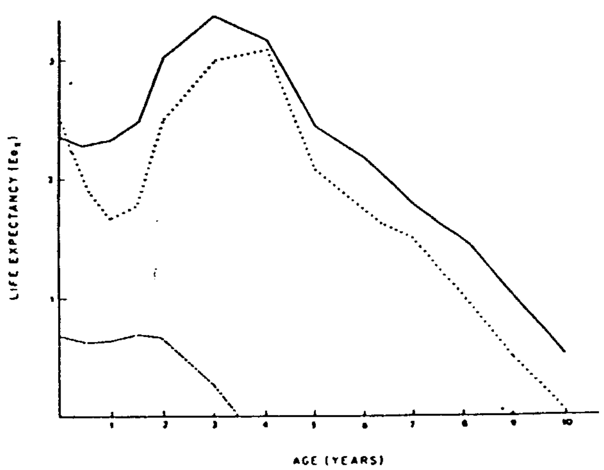


Figure 5. Life expectancy for the Dickson Mounds population for those dying within the first 10 years. Individuals with infection (---) or porotic hyperostosis (···) showed reduced life expectancy as compared to the total population (——).

age at which these lesions occur in both populations, we find that the peak frequencies in the Mississippians are more pronounced and occur about one-half year earlier than those found in the pre-Mississippian population. The earlier pattern of onset suggests that weaning may be occurring earlier in the Mississippian population.

An examination of individuals with more than one enamel hypoplasia shows an annual cycle of stress. This cyclic stress is more pronounced in the pre-Mississippian than in the Mississippian period. The intensification of agriculture may have been an attempt to meet these annual shortages.

The enamel hypoplasia might appear to be a relatively benign pathology. However, when we examine the mean age at death of people with and without hypoplasia, we find some interesting patterns. Individuals with no enamel hypoplasias have a mean age of death that is five years greater than individuals with one hypoplastic line and nine years greater than individuals with two or more hypoplasias.

A similar pattern of growth disruption and mortality in another developmental process in the Dickson Mounds population was found by George Clark and coworkers (1986). Measuring vertebral neural canal diameters, they show that those individuals with smaller diameters die earlier. The vertebral neural canal completes its growth by age four and is not able to experience catch-up growth. The growth impairment begins prior to age four, and may affect both the neurological and the immunological functions that are developing concurrently.

Finally, there are differences in life expectancy in the Dickinson Mounds skeletal population that may be related to the impact of stressors on health. For example, the life expectancy at birth decreased from 26 years in the pre-Mississippian to 19 years in the Mississippian population. At age 15, the pre-Mississippian could expect to live on the average 23 more years, while Mississippians could expect to live only 18 more years.

While the evidence unequivocally suggests that some change in the conditions of life between the pre-Mississippian and Mississippian periods resulted in a dramatic decline in the health of the Dickson Mounds population as measured by seven important indicators of health, the cause of this decline remains open.

Infectious disease and nutritional deficiencies, separately and in combination, have been a major factor in the decline in health. An increase in infectious disease may be due in large part to an increase in sedentarism. Gatherer-hunters with localized resources (such as acorns in California or marine products on the Northwest Coast) who became sedentary show significant increases in infectious disease patterns without the development of agriculture. The transition to agriculture and its subsequent intensification have been seen to lead to larger and denser settlements--factors which will increase the infectious disease load (Armelagos 1990). Decline in nutrition can be related to the intensification of agriculture with a reliance on maize. Maize is deficient in the essential amino acid lysine, and in certain trace minerals such as zinc. Robert Gilbert found a significant decrease in the zinc levels of the Mississippian bones at Dickson (1975). Wadie Bahou (1975) found that skeletons with evidence of infection had lower levels of zinc, which is an important chemical in the healing process.

Dependence on maize to such an extent that it would cause nutritional deficiencies requires some explanation. It is possible that the population grew so rapidly that it had to rely on maize as its primary subsistence source. However, while the Dickson population expanded to more than a thousand individuals in the Middle Mississippian period, the resources in the area should have been able to provide them with other sources of protein. There is no evidence of the environmental degradation that would have occurred if the population had been overutilizing the nondomesticated resources (Harn 1980). In a sense, although the menu was potentially adequate, the diet was not.

It is possible that this mystery can be solved by looking to the south. There is archaeological evidence of exchange of goods with the population center at Cahokia during the period when the health of the Dickson Mounds population is under stress. Marine shell necklaces and copper-covered ear spools which come from the Cahokia region are found at Dickson. The Dickson site, however, provides no evidence for manufacture of comparable goods for exchange. Is it possible that the exports from Dickson were perishable foods such as fish and meat? If so, essential foods were exchanged for ceremonial items and luxury goods--a practice that has been documented many times in history as well as in contemporary situations. It is important to realize that the traders may not be conscious of the long-term effects and may see this exchange as desirable, since the luxury goods have great symbolic value.

CONCLUSION

Is this pattern, of a decrease in health accompanying agricultural intensification, a universal pattern? In a study of populations that have undergone the transition to agriculture Cohen and Armelagos (1984) report considerable variability in the health consequences. On the one hand, at one site there was the suggestion that population pressures may, in fact, have *predated* the intensification of agriculture (Buikstra 1984; Cook 1984). On the other, there are a number of sites where the pattern found at Dickson--in which decline in health *follows* intensification--occurs (Cassidy 1984; Perzigian et al. 1984; Larsen 1984).

In an analysis of Middle Mississippian populations from the Eastern United States, Armelagos and Hill (1990) found no clear indication that the intensification of agriculture is always accompanied by a deterioration in health conditions. They suggest that the large ceremonial centers which emerge at this time may have been exploiting the peripheral sites, creating geographically and socially specific patterns of nutrition and health. At large ceremonial centers (such as Moundville in Alabama) while there is an increase in infectious disease (such as endemic treponemal infection and tuberculosis), there is no evidence of an increase in nutritional deficiencies (Powell 1988). At smaller sites the evidence is more like that from Dickson Mounds.

In the end, the solution to the Dickson Mounds health mystery must await future research. A study of the animal bones at ceremonial centers and peripheral sites could provide the answers. The evidence of butchering and the distribution of the bones at the sites could reveal clues about what happened to the animal protein. But as in all good mysteries, that is another story.

NOTES

1. Researchers at the calcified tissue laboratory for many years had been studying bone turnover (the amount of bone manufactured) using bone labeled with tetracycline. The fact that tetracycline labeled bone and teeth was discovered soon after children administered the drug were found to have discolored enamel in their developing teeth. Researchers were able to demonstrate that fluorophors (substances that emit fluorescence) combine with calcium and provide a "tag" or label. Calcium that is laid down in teeth and bone will fluoresce if exposed to ultraviolet light at 490 nanometers. This ability of tetracycline to label bone was used by researchers to determine the amount of bone formed during a specific period of time. Using volunteers who were undergoing biopsy, the researchers would administer small

amounts of tetracycline during a prescribed period. By examining the bone biopsy with a fluorescent light source, they could measure the amount of bone formed during the specific interval.

2. We know, for instance, that the Egyptians would often bake bread until a crust formed and the center was still uncooked. They would let the bread--called *booza*--ferment, then break it up and put it in water to continue the fermentation process necessary to make beer. Although the Nubian method of brewing beer is no longer with us, "booze," a sobriquet for beer, remains.

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