probably, cool circumstellar clouds that may be planetary systems in an early stage of formation.

The work on infrared stars has shown that the dark nebulas of the Milky Way are indeed extremely opaque. In fact, some of the clouds absorb so much of the light of the stars beyond that we would consider them to be completely opaque, for all earthly purposes. And there is every reason to suppose that even denser interstellar clouds are yet to be discovered.

Not only do the dark nebulas of the Milky Way obstruct our view of the distant stars but we have reason to believe that, given propitious circumstances, they can be the spawning places for stars. In an early stage of their development, young stars are imbedded in the interstellar matter from which they were born and are surrounded by "left-over" circumstellar clouds which in time will become planetary systems. If our interpretations are correct, a large percentage of solar-type stars have planetary systems; perhaps some of them are similar to our own.

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Paleopathology: Meeting Ground for Many Disciplines

Ellis R. Kerley and William M. Bass

Paleopathology is the study of prehistoric disease and, as such, deals predominantly with skeletal remains and prehistoric populations. In its broadest sense, paleopathology deals with diseases in animal as well as human tissues, and consequently it is a field of interest to many scientific disciplines. When infection, malfunction, or trauma affect bones and teeth, the lesions or other abnormalities can be observed and studied, and in many cases the cause can be identified.

Evidence of disease in prehistoric populations is obtained from (i) human and animal remains and (ii) prehistoric art. In the literature there are various reports of abnormalities in the bones of prehistoric animals, but the first serious controversy involving possible abnormality in a prehistoric human specimen occurred in 1896 when the eminent German pathologist Rudolf Virchow questioned the authenticity of the Neander Valley specimen, and of Neanderthal man as a human fossil population, and suggested that the Neanderthal specimens were the remains of abnormal modern men (*1*). From that time on, attempts to detect and interpret abnormalities in prehistoric specimens have increased, and in recent years the methods of investigating prehistoric disease have become more complex as new techniques have been developed. The publication in 1923 of Moodie's monumental treatise on the subject (*2*) was a milestone in paleopathology. An equally important contribution was Ruffer's study of disease among the ancient Egyptians (*3*), wherein he introduced the microscopic study of lesions in mummified tissue. Other authors have dealt with specific populations or diseases; Hooton (*4*), for example, dealt with the Pecos Pueblo, and Herbert Williams (*5*), with syphilis in the New World. Virchow himself was interested in the possibility of detecting prehistoric disease, despite his declarations against the authenticity of Neanderthal man. In the United States one of the eminent champions of paleopathology was Aleš Hrdlička.

Since knowledge of the diseases, abnormalities, and epidemiology of prehistoric populations can shed light on hereditary relationships, on the adaptation of populations to disease environments, and on the times and routes of migration of peoples during prehistoric times, it is small wonder that anthropologists have long been interested in this field. Since not only skeletal material but disease itself is the subject matter of paleopathology, many disciplines find a meeting ground in these studies.

Information That Can Be Derived from Paleopathology

Examination of individual skeletons can yield an indication of abnormalities, tumors, malformations, fractures (in particular, healing or healed fractures) (Fig. 1), and other skeletal pathology. One can document the number of skeletal abnormalities in any given population, keeping in mind the fact that not all disease is skeletal and that not all members of a population are found in any archeological site. Sometimes it is not possible to identify the disease even when the skeleton shows obvious abnormality. One cannot distinguish between severe infectious processes of relatively short duration, but it is usually possible to distinguish between infection, disturbances of growth, and simple reparative processes. It is almost always possible to distinguish between major categories of lesions, such as uncomplicated injury and infection. It is possible to distinguish between infections (Fig. 2), malformations (Fig. 3), tumors, metabolic disturbances, and the like. Though there are exceptions, usually a specimen can be assigned to a major disease category. Not infrequently the causative factor of a particular type of lesion

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can be determined. Certain types of malformation are so distinctive that we can infer the causative factor to have been lack of a specific vitamin. In the case of fractures (Fig. 1), the time that had elapsed since injury occurred can be determined by the amount of healing that has taken place. Cut wounds of bone have a fairly distinctive appearance, and the direction of slice can be determined even after extensive healing has occurred (Fig. 4). Projectile points penetrating bone (Fig. 5) leave matching wounds.

The disease pattern of a prehistoric population can be described statistically. In this procedure the number of individuals with a given lesion and the number of different types of abnormality found in the archeological population are recorded. The numbers of individuals having lesions of specific types should be recorded for each level of an archeological site. If many individuals at a given level were affected, one could infer probable famine, epidemic, or war, or, possibly, migration and first contact between populations. One might find, following migration and contact, new infectious diseases, or new hereditary diseases resulting from the introduction of new genes. Such introduced diseases would be found after the date of contact but not before. Diseases found evenly distributed throughout all archeological levels would probably be endemic, hereditary, or the result of traditional cultural practices.

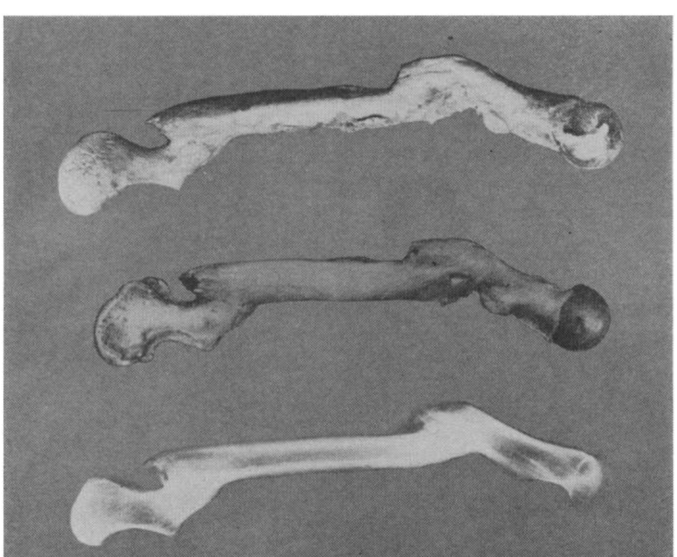
Some environmental factors causing disease and death are seasonal. Famine occurs primarily in late winter and early spring, before new crops have been harvested and before edible animals become plentiful. Floods generally occur in the spring as the snow melts. Pneumonia tends to occur when the season is changing—in early winter and early spring. So it is of some importance to determine during what season the individual was buried. The presence of insect remains (Fig. 6) often provides the key; the presence of insect exuviae and of numerous maggot remains suggests summer burial (*6*), while their absence suggests that burial occurred in the winter.

Examination of a Skeleton

In paleopathologic studies the entire skeleton must be examined, not just the areas of obvious abnormality, and any skeletons found nearby in an archeological site should also be examined for possible bearing on the abnormality. For one thing, any abnormalities that affect the skeleton generally—such as osteoporosis, osteomalacia, or some of the anemias—can be misinterpreted if only one bone is examined. Some injuries and certain other disease conditions—such as Paget's disease, syphilis, and even leprosy—affect more than one bone. Sometimes the distribution of the lesions throughout the skeleton is important in diagnosis. This is particularly true in the case of syphilis, malnutrition, and certain types of atrophy. Gross examination is still the best general method for determining prehistoric disease.

Radiologic examination is essential for assessing abnormality in archeological material. It is possible to investigate the internal structure of bones and the nature of the disease process by means of radiographs. X-ray defraction or microradiography may give some indication of the length of time a skeleton has been buried by giving information about the mineral content of the bone.

Microscopic examination of skeletal lesions is important, too, in interpreting structural changes in bones. At certain stages in fracture repair there is a considerable amount of resorption of the cortex adjacent to the fracture. At other stages there is a buildup of callus (Fig. 7). In some diseases, also, there are resorptive and reparative phases, evidence of which can best be identified through microscopic inspection of ground sections of the affected bone. Also, alterations in the normal structural and growth patterns of bone can be determined microscopically (Fig. 8), and the skeletal age of an individual can be determined through microscopic examination of cross sections of the bones of the leg (*7*). In addition, hair is examined for the purpose of determining an individual's race or of de-



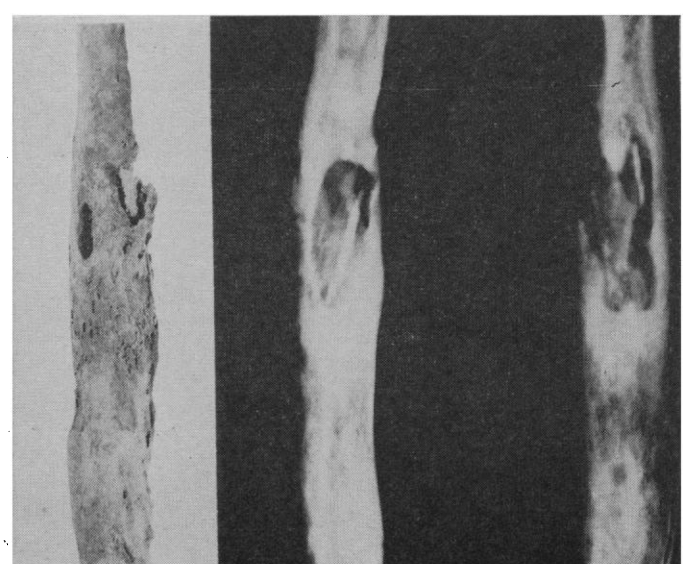


Fig. 1 (left). (Top) Photograph, (middle) drawing, and (bottom) x-ray of a right femur of a Crow Indian, about 1880, showing healed fractures. [Specimen from the Mouat Cliff Burial Site, Treasure County, Montana] Fig. 2 (right). Evidence of osteomyelitis: photograph and x-rays showing a large irregular sequestrum near the middle of the shaft of a right femur from the Rygh Site, Campbell County, South Dakota, a prehistoric Arikara/Mandan site. [Collected by Willis Hall, Mobridge, South Dakota]

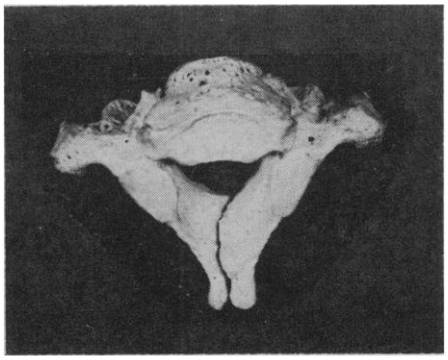


Fig. 3. Congenital malformation of a cervical vertebra, resulting in spina bifida.

tecting the presence of arsenic or other heavy metals, and skin from mummies is examined microscopically, particularly if there is any evidence of lesions, scars, tattoos, or the like. Fingernails, when present, are examined microscopically for evidences of injury or of fluctuations in the growth patterns of the nails.

It is possible in many cases to determine an individual's blood type from his skeleton by pulverizing the cancellous ends of the long bones or vertebrae and soaking the powder in saline solution before subjecting it to serologic techniques (*8*). In the future it may be possible to correlate certain anemias with certain serologic reactions in the skeleton, but at present only the ABO blood types can be determined in purely skeletal material. There are some indications that, under certain postmortem conditions, the antibody reactions to even these blood types can be misleading (*9*).

Microradiography in combination with light microscopy can show minute variations in calcification, in areas adjacent to skeletal abnormality, which result from arrested growth during periods of physiologic crisis. Radiographs may show these arrested-growth lines near the ends of the long bones (*10*), and the time from severe illness to death (or to adulthood) can be calculated from the distance from the line of arrested growth to the epiphyseal line (*11*). The electron microscope has not as yet been brought to bear on much archeologic material, partly because much of the organic structure has often been lost and partly because it is difficult to prepare purely skeletal material for electron-microscopic processing. It is probable, however, that this instrument will prove useful in assessing archeologic skeletal abnormality in the future, perhaps in the identification of specific viruses or bacteria.

Other Sources of Information

Information concerning the disease pattern in prehistoric populations is derived from paintings, figurines, and pottery, as well as from skeletons. Artifacts depicting certain types of disease have been found in Egypt, in parts of the Near East, and in Central and South America (*12*).

Therapeutic devices are often found near archeological skeletons; these include splints, braces, surgical instruments, and sometimes bone or stone figures. Of course, kidney stones and gallstones are occasionally found with skeletons (*2*).

Analysis of the climate and ecology that existed at the time an archeological population inhabited a particular area can be enlightening in terms of the disease pattern. Some parasites live only under certain climatic conditions or only in certain areas. One would not expect to find hookworm among the Eskimo. On the other hand, some diseases are endemic to certain regions, and probably also were in the past. Provided there has been no severe alteration of climate or environmental conditions, it is unlikely that a particular disease would have been endemic, in prehistoric times, in areas now very different from those where it is endemic today.

One major controversy in paleopathology has been the possibility that syphilis originated in the New World; among the skeletal specimens available there are some that support the view that it did (*5*). The problem of the origin of syphilis is an interesting example of the types of data that can be brought together to provide information concerning prehistoric disease patterns. Pre-Columbian skeletons from various parts of the New World exhibit lesions that resemble those of syphilis in modern populations. These range from lesions that might possibly have been luetic to others that are exact duplications of modern syphilitic bone lesions. For years many reputable scientists have interpreted these as evidence that syphilis was present in the New World before the time of Columbus and probably originated here. Other equally reputable scholars have maintained that one cannot be sure what these lesions represent, since the treponema spirochetes that are known to cause syphilis are no longer present in skeletons. They argue, further, that syphilis and yaws produce similar lesions, that both are spirochetal in ori-

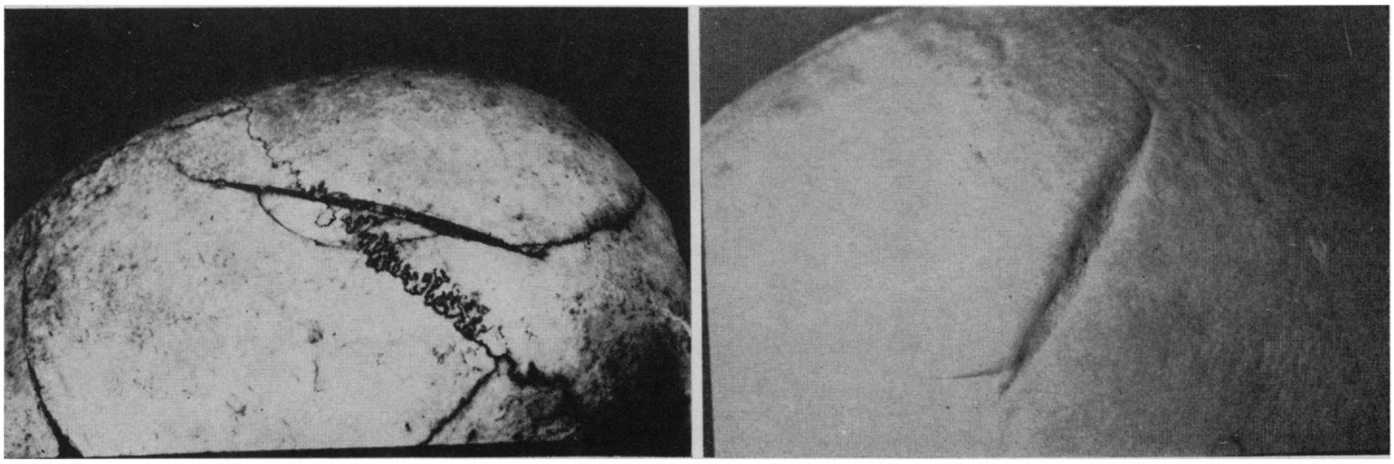


Fig. 4. (Left) Sioux skull showing saber cuts received at time of death. (Right) Skull showing old healed saber cut several years after injury.

gin, and that therefore one cannot be distinguished from the other. This view tends to confuse the disease syphilis, which had been known and recognized for centuries before the spirochete was discovered, with the diagnostic tests for syphilis devised by Wassermann and Kahn.

Syphilis, which was named for Fracastoro's tragic hero, was enjoyed by the populace of Europe without benefit of any knowledge concerning the causative microbe. History records the first appearance of this disease in Barcelona in 1493, when de Isla treated Vincente Pinzón, captain of the *Pinta*, for the disease which later came to be known as the great pox that spread across Europe (*13*) with the advancing and retreating armies of France, Spain, and Italy. The skeletal lesions of this disease were well known, and it is interesting to note that most of the early physicians who had wide experience in dealing with syphilis recognized the skeletal lesions in cases of known syphilis and in several of the pre-Columbian specimens (*5*). With the increased dependence on serologic tests as diagnostic tools and the advent of antibiotics came a decrease in the frequency of tertiary syphilis. Specimens of skeletal lues are seldom seen today except in older museum collections, such as the extensive collections of the Armed Forces Institute of Pathology Medical Museum in Washington, D.C.

Some of the pre-Columbian New World skeletons have lesions which are typical of those caused by known and documented syphilis in some of the older pathologic collections. It may be said with certainty that syphilis *can* cause such lesions and that they usually have a particular distribution throughout the body, the frontal bone and the tibiae, fibulae, and distal humeri being the areas most commonly affected.

On the other hand, very few diseases other than syphilis are known to cause such lesions in bones. In some skeletons from the southeastern United States the lesions are found in the skeletal areas affected by syphilis and are of the stellate type found in syphilis (Fig. 9), where destructive foci are surrounded by reparative sclerotic bone. Other disease processes that might produce skeletal lesions similar to those found in these specimens would include the following.

1) Osteomyelitis, which is a rather

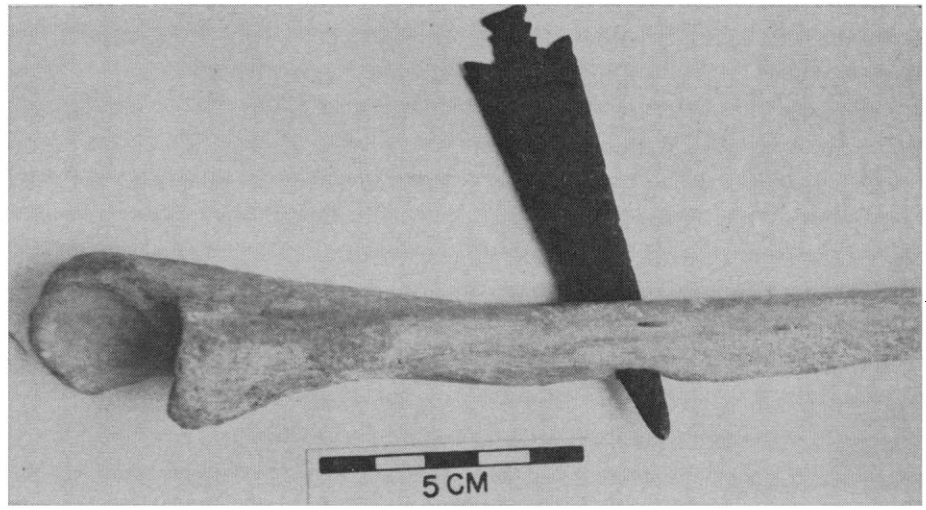


Fig. 5. Right ulna (possibly of a Sioux Indian) penetrated by a metal arrow. [North Dakota State Historical Society]

active destruction of cortical and cancellous bone, accompanied by the formation of a sleeve of reactive involucrum. Only in cases of very low-grade infection does one find destruction and repair of bone so closely adjacent as in luetic skeletal specimens.

2) Tuberculosis. This is a low-grade inflammation, but it affects the spine with greatest frequency (which syphilis does not) and the epiphyseal regions of long bones.

3) Paget's disease. This affects the skull and tibiae as lues does, but Paget's disease expands the medullary cavity, whereas syphilis contracts it (*14*). In the skull, Paget's disease usually affects the parietals first, whereas syphilis most commonly strikes the frontal bone first and usually produces discrete foci of inflammation surrounded by sclerotic reparative bone.

4) Yaws (frambesia). This may produce bone lesions resembling those of syphilis, and it is caused by a spirochete closely related to the *Treponema pallidum* of syphilis. Some skeletal lesions could be the result of either yaws or lues, but certain lesions are distinctively syphilitic in appearance and distribution. These include the small, focal lesions of bone in areas of sclerotic reactive bone, the stellate scars of the frontal bone, and lesions having a typical distribution in frontal bone, tibiae, distal humeri, and hands (*15*).

The epidemiologist contributes the additional information that, whereas syphilis is not limited by climate, since it is venereally contracted, yaws is a dis-

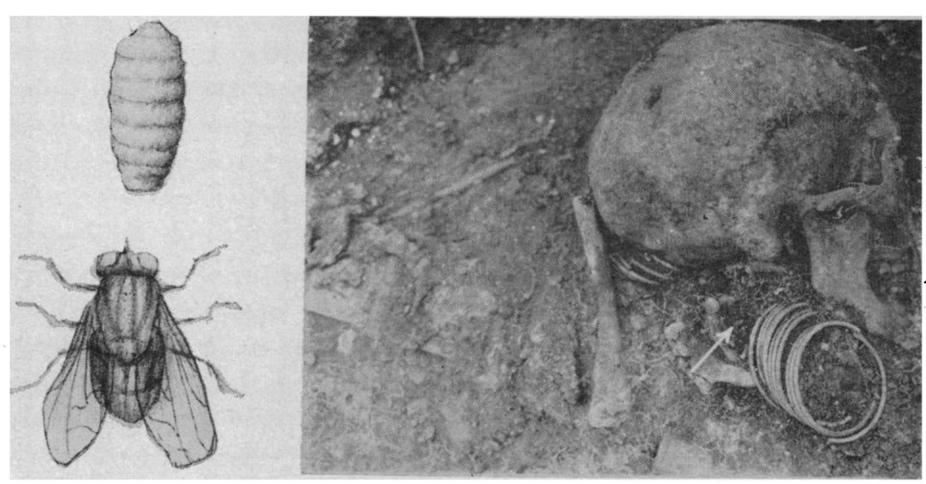


Fig. 6. Photograph of Arikara Indian burial (about A.D. 1800) from the Leavenworth Site, Corson County, South Dakota. The arrow points to the pupal case of a sarcophagid flesh fly associated with the burial. The pupal case and the fly are sketched at left.

ease of the tropics and has never been endemic to the United States.

Quite often it is not possible to say with certainty that any given lesion represents a specific disease. However, if a lesion on a prehistoric bone is precisely similar to lesions known to be caused by a given disease in living individuals and if no other disease is known to cause similar lesions, it is reasonable to infer that the lesion on the prehistoric bone was caused by the same factor that causes such lesions in modern populations.

Interested Disciplines

Because of its varied aspects, paleopathology is of interest to workers in many disciplines.

Physicians in general are interested in the origins of diseases and in fluctuations in the prevalence and virulence of certain diseases in historic and prehistoric times. Having some knowledge of past history, one is better able to predict the course of future events.

Orthopedists in particular are interested in paleopathology, since it deals primarily with skeletal disease and skeletal evidence of disease. Such studies enable them to see the consequences of untreated fractures, injuries, growth abnormalities, and other diseases of the skeletal system and of untreated bone tumors and arthritis. Among the artifacts of certain prehistoric populations, such as the early Egyptians and some of the American Indian groups, are early forms of splints, braces, and other orthopedic devices, and orthopedists can compare the effectiveness of these early forms of treatment with that of modern methods.

The radiologist also finds much of interest in paleopathology. In dealing with prehistoric, as with modern, skeletal abnormalities, x-rays of affected areas are essential to an adequate diagnosis and understanding of the disease process involved. The radiologist is able to interpret bone diseases, as revealed by x-ray, whether they are prehistoric or recent. However, lesions in ancient bones often look quite different from similar lesions in living persons (or in fresh cadavers), and many orthopedists and radiologists welcome the opportunity to examine dry, macerated specimens of known pathology.

Epidemiologists study the temporal and geographic distribution of diseases and are interested in tracing evidence of disease in populations back into prehistoric times, particularly evidence of epidemic diseases such as leprosy, syphilis, malaria, and tuberculosis.

Many obstetricians are interested in the treatment of pregnancy and the methods of obstetric delivery in both prehistoric and modern primitive societies, and in abnormalities of fetal development. Abner Weisman, a New York obstetrician, has collected numerous prehistoric clay figurines from Mexico that depict possible abnormalities and treatment. Surgeons study the numerous specimens showing evidence of surgery which are to be found in archeological collections. Many of the pre-Inca and Inca skulls show evidence of trephining (*16*). The instruments used in such operations have been preserved, and the operations have been depicted in the art of the Incas and the Egyptians.

Prehistoric remains are usually skeletal, but mummified remains which show evidence of soft-tissue lesions are occasionally recovered. The skeleton itself can provide evidence of prolonged cardiac or pulmonary insufficiency, of tuberculosis, and of the anemias—all matters of interest to the internist as well as to the anthropologist.

Dentists (*17*) and orthodontists study the teeth of prehistoric peoples, particularly in populations that had a gritty diet. They are interested in the growth of untreated abnormal teeth, in the effects of diet upon teeth and tooth wear, in the alignment of teeth, and in the relation of dental caries to diet and drinking water. Orthodontists are particularly interested in the effects of tooth wear on the spacing of teeth and on the angulation of the rami of the mandibles in prehistoric populations where the wear was excessive.

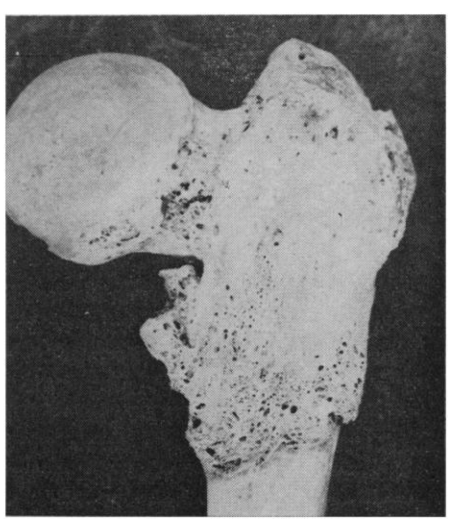


Fig. 7. Reparative callus on the dorsal aspect of a right femur several months after fracture.

Manifestations of the diseases of old age and of senility in primitive and prehistoric populations provide the gerontologist with information that has bearing on modern problems of biologic aging. A psychiatrist finds much of interest in the mutilations, scarifications, and decorations of prehistoric peoples and in burial customs and other cultural practices that have left their marks upon the skeleton or are depicted in stone or paint.

Among specialists in fields other than medicine, the physical anthropologist has an important role in these investigations. It is his task to describe the physical characteristics of archeological populations in terms of the approximate age at death of individuals, the sex ratio, the ages of survival for male and female, the general stature and physical appearance of the population, and the diseases manifested in the skeletons. He is particularly interested in the physical effects of cultural practices (effects such as cranial deformation or alterations in bone structure from squatting), in growth, and in the response of the skeleton to disease. Genetic skeletal characteristics and hereditary diseases that have affected the skeleton indicate hereditary differences or similarities between populations. So do growth patterns and differences in stature. Evidence of trauma is found in some of the earliest human remains, where bone has formed in an injured muscle (myositis ossificans). The left femur of *Pithecanthropus erectus* (Fig. 10) shows an exostosis which probably originated in this way. Occasionally misinterpretation of a skeletal abnormality has led to an erroneous conclusion. One example is the reconstruction of Neanderthal posture from one skeleton which Straus and Cave show (*18*) to have been severely affected by osteoarthritis.

In the field of the history of medicine, the physical anthropologist has furnished much information on early amputations. Stewart (*19*) has found evidence of the removal of an arm in the Neanderthal skeleton from Shanidar, Iraq, dated about 40,000 B.C. Brothwell and Møller-Christensen (*20*) report a possible case of amputation from Egypt, in a skeleton dated about 2000 B.C. (IXth Dynasty). Various explanations of amputation of parts of the hands or limbs have been proposed: this may have been an expression of mourning, a result of battle injuries, surgical amputation required by infection, or a form of punishment, especially of thieves or prisoners. Brothwell and Møller-Christensen make a strong case for their conclusion, from study of the Egyptian skeleton of 2000 B.C., that amputation of the right hand was a means of recording the number of prisoners after a conflict; a scene painted on the walls of the temple of Rameses III shows this recording procedure.

The cultural anthropologist (a category which includes the archeologist) looks for the relationship of skeletal injuries and physical characteristics of skeletons at the archeological site to pictorial depiction of cultural practices, migrations, contacts with other archeologic populations, and warfare. The ethnologist is interested in prehistoric medical practices as well.

Geneticists are interested in the evolution and distribution of hereditary diseases in prehistoric populations, and in the possibility of evaluating the influences of heredity versus those of environment in producing certain effects upon the skeleton.

Human paleontologists and evolutionists study the selective force that certain injuries and diseases may exert on evolving populations (*21*). The relationship between malaria and sickle-cell anemia is of interest, since populations with high frequencies of sickle-cell genes may have a greater immunity to malaria than those lacking such genes. Sickle-cell anemia often prevents the effective breeding of homozygous individuals and may strongly affect the nature and course of evolution in a population.

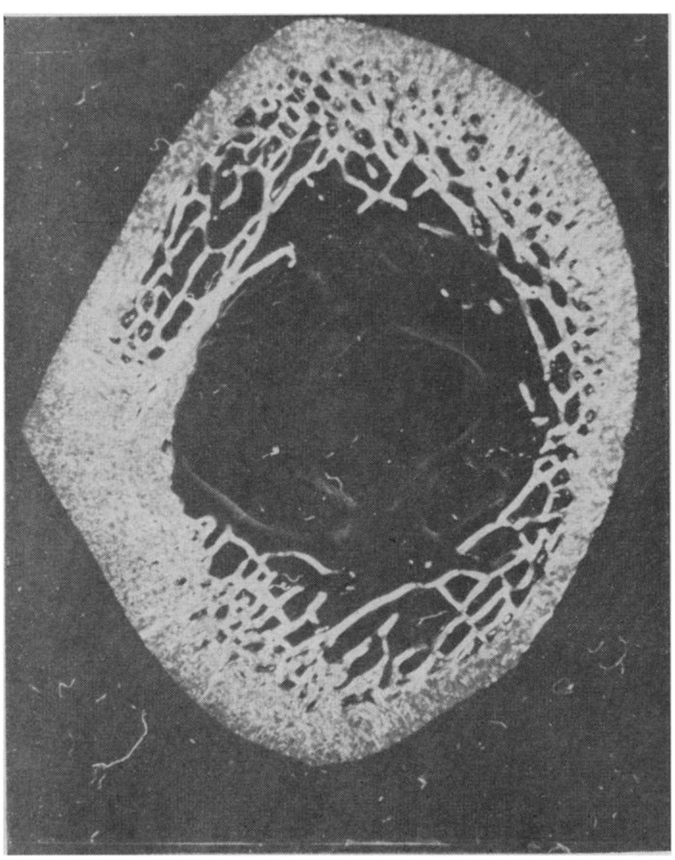
Zoologists and vertebrate paleontologists investigate prehistoric distributions of skeletal lesions in extinct species, and life forms in the entire zoologic realm.

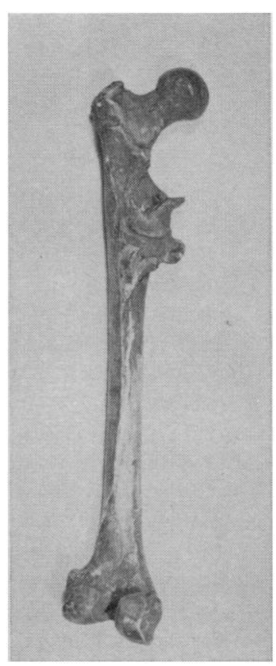
Historians are interested in the events leading up to the beginning of recorded history—for example, in the prehistoric occurrence of diseases, such as syphilis and leprosy, which became important during historical times.

Present and Future of Paleopathology

Thus, paleopathology is at present a field of interest to many disciplines rather than a science in itself. As such, it can call upon methods and techniques derived from many fields. Information is obtained from the orthopedic pathologist, the orthopedist, and the radiologist, each of whom examines prehistoric diseased material from his own specialized point of view. It is also obtained from the physical anthropologist, the archeologist, the ethnologist, the paleontologist, the geologist, and, occasionally, the historian, for certain eras.

Each interested discipline contributes information to the general field and derives information from the general store of knowledge. In the future more techniques will be developed for examining diseased prehistoric material, but it is unlikely that there will ever be an adequate substitute for the comparison of lesions in prehistoric bones with gross radiographic and microscopic patterns associated with known diseases. If paleopathology is to provide useful information concerning the





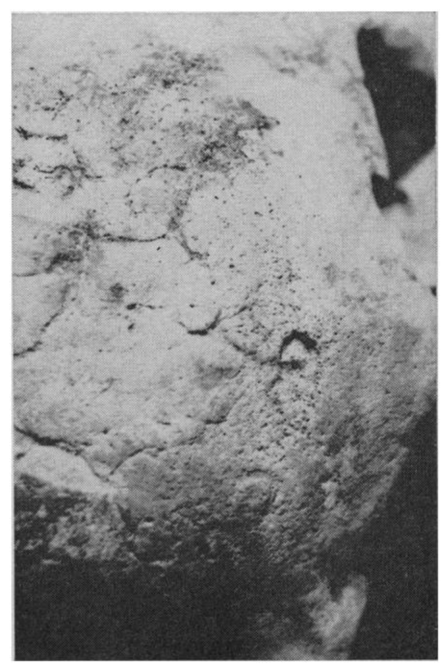


Fig. 8 (left). Photograph (taken in polarized light) of a ground cross section of the mid-shaft of an adolescent tibia from Wetherill Mesa, showing abnormal enlargement of the shaft and medullary cavity that occurred over a period of several years during childhood and adolescence. Fig. 9 (middle). Frontal bone of a Florida Indian, probably of pre-Columbian date, showing stellate scars typical of syphilis, foci of inflammatory resorption, and reactive reparative bone. Fig. 10 (right). Photograph of a cast of the left femur of *Pithecanthropus erectus*, showing exostosis.

people in whose skeletons evidence of ancient diseases has been found, the disease process must be understood, not merely identified. Only in this way can such studies add to our knowledge of the daily lives, hereditary relationships, cultural practices, diets, and contacts of prehistoric peoples.

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Antireductionism and Molecular Biology

Though the antireductionist thesis is unwarranted, research in classical biology may well be of value.

Kenneth F. Schaffner

The question of whether biological organisms are anything "more than" chemical systems has often been confused in the minds of many thinkers with the question of whether there are alternative ways of studying biological organisms. It seems to many that an unequivocal no to the first question implies that the chemical description and explanation of a biological organism is the only one. I think that both the history of genetics and simple prudence indicate that this implication is wrong.

Associated with this question of what point of view to take have been claims asserting that the chemical description is an essentially incomplete one for a living organism. Distinguished biologists and physicists have argued in the past, as well as quite recently, that it is *impossible*, not merely difficult or impossible *at the present time*, to explain the behavior of living organisms on the basis of their chemical constitution. In this article I take into account both the question of the point of view and the question of the impossibility of chemical explanation of vital phenomena. Bentley Glass (*1*, p. 223), Walter Elsasser (*2–4*), and Barry Commoner (*5*) have had things to say on these topics in recent years, and I think that it is important to assess what is correct and incorrect in what they claim (*6*).

I begin with an argument which Bentley Glass has proposed to demonstrate that chemical explanation—of the type molecular biologists might attempt—is insufficient to account for existing biological laws, and then follow up this argument and deepen it by considering the thesis which Elsasser developed in several articles in the *Journal of Theoretical Biology* (*2–4*). The relevance to Barry Commoner's concerns of the position which I take will be obvious I think, so I do not need to recount what he says.

In his article entitled "The relation of the physical sciences to biology—indeterminancy and causality" (*1*, pp. 241–243), Bentley Glass states:

> Statistical behavior . . . exists at all levels of organization, from elementary particles to galaxies. It clearly operates at all biological levels, from the molecule to the organism, . . . The Mendelian ratios depend upon the equal probability of an egg's fertilization by any one of two or more kinds of sperms when these kinds exist in equal numbers.
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> The randomness of the behavior of the units involved at one level does not necessarily depend on the randomness of units at lower levels of organization, [and the] . . . laws of science . . . arising directly from the nature of chance, and the mathematical expression of probabilities do not seem to be reducible to laws at a lower level of physical organization, because they describe the random behavior of entities at one particular level of organization.
>
> [Accordingly] we may conclude that the statistical laws of one level of organization [for example the cellular] are not reducible to the statistical laws of another [for example, the chemical].

This is an intriguing argument but one which I believe contains a *non sequitur*. The fact that a macroscopic probabilistic generalization—say, that the average number of times the "head" side of a fair coin will turn up in 1000 throws will be near 500—can be asserted does not warrant the claim that this relative frequency could not have been explained in terms of microscopic variables. There easily could have been a randomization of the initial (microscopic) conditions. Of course one *need* not give a microscopic explanation, but Glass's claim is far

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