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Biocultural Perspectives on Stress in Prehistoric, Historical, and Contemporary Population Research

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ABSTRACT Stress, a concept addressing the consequences of disruptive events on individuals and populations, can be a useful integrative idea. The stress process has much in common with its sister concept of adaptation. However, where adaptation focuses on "adaptive" or positive consequences, stress redresses an imbalance by focusing on the costs and limits of adaptation.

In this paper we first review the interdisciplinary roots of the stress concept. While most stress research derives from research in environmental physiology, Selyean concepts of stress (involving increased catecholamine and corticosteroid output) have forced an expansion toward greater concern for perceptual and psychosocial stressors. What is largely missing from all traditions, however, is concern for sociopolitical processes which are not easily adapted to and consequently are persistent and pervasive causes of stress.

Studies of stress in prehistoric, historical, and contemporary populations by biological anthropologists vary, in a complementary way, as to ability to delineate aspects of the stress process. Whereas the paleopathological methods of the prehistorian provide a suite of skeletal indicators of stress response, and the demographic measures of the historian provide a detailed analysis of consequence, a wide variety of techniques for examining all levels of the stress process are potentially available to those studying contemporary populations. In order to better utilize information from different levels of analysis one needs to focus on measures of stress, such as infant mortality, which are accessible at all levels. Biological anthropologists are in a unique position to elucidate the human condition if, via concepts such as stress, attention is paid to both human adaptive and political economic processes.

This overview of the concept of stress has been written in response to a variety of recent trends affecting biological anthropology. On the most general level, subfields within biological anthropology have increased in number and methodological sophistication. While this trend is evidence of the vitality of our discipline, a side effect is a decrease in ability to keep up with developments in areas of bioanthropology peripheral to one's central interests. Increased subfield separation threatens our ability to maintain the concepts, perspectives, and ideals that link us as a field of study.

In the face of the above trends, one mechanism for maintaining our connectedness is to reconsider shared concepts and perspectives. It is in this light that we critically evaluate the concept of stress, a concept that is increasingly used, explicitly and implicitly, in a diverse range of areas of anthropological inquiry. As a ubiquitous idea, addressing the consequences of disruptive events on the body and soul of individuals, stress constitutes a pervasive organizing force in our daily lives. Stress etches itself into our biology and behavior, usually initiates a series of biobehavioral countering responses, and ultimately bears consequences for our social relations, ideological constructs, and evolutionary trajectories. In an evolutionary sense, if adaptation can be considered as the engine running selective processes, then stress must be regarded as its primary fuel. Whether stress is viewed in its evolutionary dimensions or more immediately in terms of consequences and responses to an array of contemporary conditions, the biocultural scope of the problem makes its interpretation an important anthropological endeavor.

Following well-developed research agendas on stress in other disciplines, most notably psychology and physiology, the 1980s have witnessed an increase in research on stress in biological anthropology. This activity is best seen in studies of adaptation in two different settings—the prehistoric and contemporary. Stress is now central to the notion of reconstructing adaptation via paleopathological and paleodemographic methods (cf. Goodman et al., 1984a). And the view of stress originally proposed by Selye (1936) as a nonspecific hormonal reaction to a wide variety of noxious or stressful stimuli has recently infused human adaptability research[1] (Brown, 1981; Dressler and Bernal, 1982; Hanna et al., 1986; McGarvey and Schendel, 1986).

While the concept of stress is used in a variety of areas of anthropological research (Dirks, 1980, on response to food shortage and other "disasters"; Eder, 1977; and O'Neill, 1986, on loss of culture; and Graves and Graves, 1979; and McGarvey and Baker, 1979, on migration and modernization), it has infrequently been focused upon in a general or theoretical manner. Interesting exceptions are Spradley and Phillip's (1972) discussion of the potential for cross-culturally valid measures of stress and Young's (1980) anthropological critique of the stress-related assumptions of life-change research. Finally, Brown's (1981) paper "General Stress in Anthropological Fieldwork" comes closest to a general review, especially from a bioanthropological perspective. However, it focuses upon the "Selyean" concept of stress (described below) while ignoring the more general applications of this idea to demography and paleopathology and much of the concept's applicability to sociopolitical processes (Blakey, 1985). Furthermore, a significant expansion of this field has occurred since the appearance of Brown's paper.

It is, therefore, our objective to consider how the stress concept has been used, and may be better used, to bind interpretation of biological and social phenomena between periods of time and across data sets with differing parameters and attributes. Because much of our past research has focused upon examples of biocultural interplay within an adaptive perspective yet has differed in time frames considered and methodologies employed, we will explore commonalities in the stress process over three time periods for three rather different populations in transition. The first example uses skeletal biological techniques to reconstruct stress patterns during prehistoric transitions, occurring over centuries and millennia, for populations from Sudanese Nubia and Illinois (see Goodman et al., 1984b; and Martin et al., 1984, on the Illinois River Valley and Sudanese Nubia, respectively). The second example relies on historical demographic techniques for study of the transition in 19th-century Massachusetts from an agrarian-based economy to one of mixed commercial agriculture and industry (see Swedlund, in press). A final example follows the biobehavioral adjustments of a contemporary Andean peasant population which, over the past two decades, has undergone increased commercialization of its agrarian economy (see Baker and Little, 1976; Thomas et al., 1979).

More comprehensive review of biocultural issues pertaining to each of these general areas of research can be found in Huss-Ashmore and co-workers (1982) and Goodman and co-workers (1984a) for prehistory; Swedlund (1978) for the historic

[1]Terms such as "adaptation," "adaptive response," and "adaptive perspective" are frequently used throughout this paper. Adaptation is best thought of as a process of adjustment to environmental constraints. While adaptation can also be equated with Darwinian fitness, the adaptive perspective is quite a bit broader. Adaptation, or adaptive responses, include physiological, plastic, or nongenetic responses as well as those that confer an evolutionary advantage.

transition; and Thomas and co-workers (1979) for contemporary population ecology and adaptation. Assuming that prior reviews provide sufficient background, we will neither attempt an extensive review of the literature in the areas of stress, disease, or socioeconomic transition nor summarize in any detail contributions within prehistoric skeletal biology, historical demography, or contemporary human adaptability. Rather, this paper is a first attempt to explore routes for a more comprehensive interpretation of stress and disease which better utilizes the power of the anthropological scope of inquiry and the diversity of the discipline's analytical approaches. Specific purposes of this review are thus to 1) trace the origin and development of the stress concept in allied fields, 2) review the use of this concept in three areas of biological anthropology: paleopathology, historical demography, and human adaptability, 3) evaluate and compare uses of the concept of stress at these three levels of analysis, and 4) suggest ways that the idea of stress might be "recast" in light of a more dynamic and dialectical view of human adaptability.

INTERDISCIPLINARY ROOTS OF THE STRESS CONCEPT

The most prevalent use of the concept of stress in biological anthropology before the 1980s was as an *environmental condition* putting strain on the organism (Iscan, 1983). Examples of this usage are Siegel and co-workers (1977) on "heat stress" in experimental skeletal biology and Stini's (1969) pioneering use of the concept of "nutritional stress" in studies of adaptation to chronic undernutrition. In the late 1970s, one sees a subtle shift in perspective to also viewing stress as *physiological change,* a conception that derives from the work of Selye (1936, 1950). Changes in physiology, and less directly changes in development and health, are seen as indicators of the "state of stress" experienced by the organism, a state having great adaptive significance (Frisancho and Baker, 1970; Mazess, 1975; Rose et al., 1978).

The concept of stress as environmental factor derives from environmental physiology (Little, 1983), whereas stress as physiological change comes from Selyean stress. These two varying uses of the concept of "stress" have caused a great deal of confusion both within and outside of biological anthropology, although both perspectives are ultimately concerned with the adaptive process. For clarity and consistency, in this review we will follow the Selyean vocabulary in considering stress to be the biobehavioral response to environmental conditions. These stress-producing conditions are variously labelled stressors, insults, noxious stimuli, and the like.

The following section provides an overview of the development of the environmental physiological and Selyean perspectives on stress. Since the environmental physiology perspective is better known to biological anthropologists (cf. Damon, 1975; Frisancho, 1981; Little, 1983) and the Selyean stress perspective is increasingly being adopted, greater emphasis will be given to the latter.

Stress and environmental physiology

Though derived from the same historical roots as Selyean stress—namely, the works of Claude Bernard (1872) on the maintenance of the "milieu interior" and Walter Cannon (1929, 1932, 1935) on the concept of homeostasis—the environmental physiology paradigm posits differences in loci of stress causation, mechanism of physiological activation, and subsequent measurement techniques. The fundamental model utilized by environmental physiologists (Fig. 1; Prosser, 1964; Baker, 1974, 1975; Slonim, 1974) traditionally proposes a perturbing condition external to the organism which is capable of eliciting a physiological strain (or stress, in Selyean terminology). While perceived threats, the class of stressors most central to Selyean stress, can be incorporated into the environmental physiology model (Harrison and

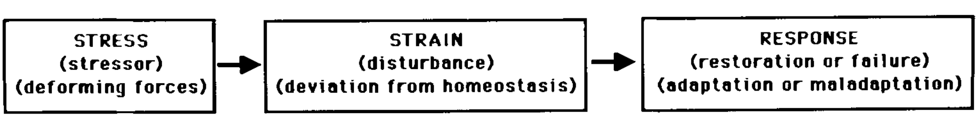

Fig. 1. Environmental physiology model of the stress process (modified from Little, 1983).

Jeffries, 1977), biotic and physical stressors are most central to it. The environmental physiology model has guided much of the inquiry of biological anthropologists into human adaptability (Little, 1983) and is modified to the investigation of stress in prehistoric populations by Goodman and co-workers (1984a; also see Huss-Ashmore et al., 1982; Martin et al., 1985; Fig. 2).

Were single stressors to operate in isolation, the above model might prove to be adequate. Assessment of responses, however, is considerably complicated by the interactive effects of other stressors. Emerging from this realization has been an increased consideration for adaptation to multistressor conditions. Here it becomes important to examine how adaptation to one stressor may transfer benefit (cross-adaptation) or interfere with adaptation to other stressors. While more complicated, consideration of adaptation to multistressor conditions provides a clearer picture of the adaptive "decisions," with attendant costs and benefits, faced by individuals and groups.

In order to assess the consequences of this adaptive dynamic, Mazess (1975) has proposed that evaluation be based on effects relative to a series of adaptive domains. At the individual level these include 1) physical performance (exercise and motor abilities, skills), 2) nervous system functioning (sensory motor and neural functions), 3) growth and development (progression in rate and attainment), 4) nutrition (meeting requirements, utilization efficiency), 5) reproduction (survival, reproductive advantage), 6) health (morbidity mortality, disease resistance), 7) cross-tolerance and resistance (generalized stress resistance), 8) affective functioning (happiness, tolerance, sexuality), and 9) intellectual ability (learning, expression). At the population level evaluation of benefit includes reproductive advantage (selection, fitness), demographic optimality (age-sex structure), spatial-temporal spread (dominance, persistence), and energetic or ecological efficiency (biomass, numbers).

As benefit in one domain does not presume benefit in other domains, Mazess (1975) also cautions against automatically transferring adaptive interpretation from one level to another. For example, an "adaptation" at the infraindividual level (such as increased tissue capillarity in response to hypoxia) will not always provide benefit at the individual level (such as on the adaptive domains of health and physical performance), and these domains certainly should not be extrapolated up to the level of the population.

Selyean stress

Selyean stress research has developed through five roughly temporal paradigms. For over 20 years, or since Appley and Trumbull's (1967) edited volume on psychological stress, stress research has been clearly perceived as an area of interdisciplinary research. This field has evolved from generalities about biological responses to stressful conditions to a large field that incorporates much of the research connecting social environments to health (Kasl, 1984).

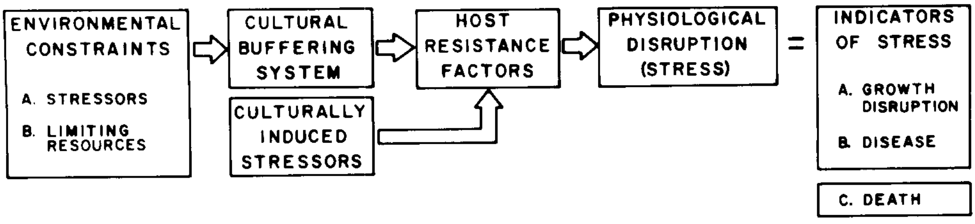

Fig. 2. Stress model adopted for use in skeletal populations. Although stress, as a physiological disruption, cannot be directly measured, a variety of skeletal changes may be used to infer stress (from Goodman et al., 1984a).

The general adaptation syndrome and the concept of nonspecificity

While research in Selyean stress also rests on the pioneering work of Claude Bernard and Walter Cannon, the central notions of stress are most clearly evolved from the work of Hans Selye (1936, 1950, 1955, 1956). In 1936, Selye first described in a half-page communication to *Nature* his observations on the "nonspecificity" of response in mice to a wide variety of noxious stimuli. What Selye invariably observed was a syndrome involving thymus atrophy, adrenal cortical involution, and duodenal ulcers. He proposed that these morphological changes were the result of a general and stereotypic endocrinological process called the "general adaptation syndrome," or GAS.

This syndrome was postulated to involve three stages: 1) initial alarm, 2) resistance, and 3) adaptation or exhaustion. The strengths of Selye's emphasis on nonspecificity included its fit to prevailing theory on internal regulation, and testability on a morphological and perhaps behavioral level. More importantly, the view that organisms respond to a diversity of noxious stimuli in the same "stereotypic" fashion had profound implications for the organization of research in the social and biological sciences. It suggested that the study of this response would provide considerable insight into the adaptive process. Like the environmental physiological perspective, Selye's view of adaptation focused on maintaining a steady state. Implied within this view is a notion of natural selection as favoring organisms that can maintain this steady state. Unlike his predecessors and environmental physiologists, however, Selye thought the maintenance of the steady state could be seen as highly integrated and nonspecific. Given the above, it is not surprising that the Selyean view of stress has gained wide acceptance (Mason et al., 1976).

By 1970, the endocrinological substances and axes responsible for the morphological end-states originally described by Selye had been outlined. These "stress response axes," principally the pituitary-adrenal cortical and the sympathetic-adrenal medullary, led to the release of 17-hydroxycorticosteroids and catecholamines, respectively (Axelrod, 1975, Bajusz, 1965, Mason, 1968a,b). In fact, so closely related is the activation of these endocrinological axes to Selye's concept of stress that their activation is now referred to as the "Selyean stress" response (Kagan, 1975).

Hydroxycorticosteroids and catecholamines (epinephrine and norepinephrine) act throughout the body in initiation of alarm and increased resistance (Selye, 1973). Of interest is the adaptiveness of this response. According to Selye and others, under conditions of real threat, the response is generally adaptive if both the threat and response are short-lived. However, chronic or repeated activations of the stress response may lead to a variety of functional disorders, including cardiovascular disease, ulcers, hypertension, and immune suppression (Asterita, 1985; Brown, 1981). Conditions which provoke chronic or repeated activations include perceived stressors as well as conditions, such as sociopolitical events, for which individuals perceive little control (Blakey, 1985; Goodman, 1984).

The importance of perception to the Selyean stress response is best illustrated by the work of John Mason and colleagues. While early studies tended to support the nonspecificity of responses of these two axes to noxious stimuli, Mason has provided a series of critical reviews of this notion (Mason, 1968a,b, 1971; Mason et al., 1976). Mason convincingly makes two important points. First, some "stressful" conditions such as hyperthermia and hypocaloric stress *do not* cause increases in either catecholamine or corticosteroid output. This lack of response reaffirms the adaptive conservation of energy in the face of caloric limitations. Second, *perceived stressors* are among the most consistent and potent activators of the sympathetic-adrenal medullary and pituitary-adrenal cortical axes. Mason concludes that the first point disproves the notion that the GAS is a nonspecific response mechanism. He then proposes that what has been "discovered" is a response system that is specific to a broad class of stressors—those that are perceived as threatening. In short, while the notion of nonspecificity of adrenal medullary and adrenal cortical activation has been disproved, it is clear that perceived stressors consistently do activate these endocrine glands. What then emerges are examinations of how perceived stress (or psychosocial factors) is a risk factor for illness via the mechanism of Selyean stress.

Integration: Psychosocial stressors, physiological stress, and disease

This second theme in stress research revolves around the causal role of perceived stressors in disease via the mechanisms of increased Selyean stress. This perspective, exemplified in the work of Levi and co-workers in Stockholm (cf. Kagan and Levi, 1974; Levi, 1972, 1971, 1975a,b, 1978, 1980), attempts to combine two main research questions. One is concerned with further understanding the causal role of psychosocial factors in increasing Selyean stress. The second is an extension of the first and concerns the causal role of Selyean stress in diseases. The main objectives of these studies are to link psychosocial factors to stress, on the one hand, and stress to disease, on the other (Fig. 3).

Through a large number of creative research projects, Levi and co-workers have demonstrated the strengths of the two principal links. For example, Levi and colleagues were among the first to link Selyean stress with "real life" situations such as shift and "piecework" (Levi, 1972) and urban commuting (Lundberg, 1976) while also showing how Selyean stress might predispose one to heart disease, infections, and other ailments (Palmblad, 1977; Theorell et al., 1972).

The Levi model is exemplary for its broad interdisciplinary perspective and its view of Selyean stress as a *mechanism* for linking psychosocial factors to disease. However, a variety of problems in this research agenda has led to its being replaced by narrower views of the stressor-stress-disease linkage. Most important is the measurement of Selyean stress against the time scale of disease. Despite some recent advances in methods, Selyean stress remains difficult to measure in large samples

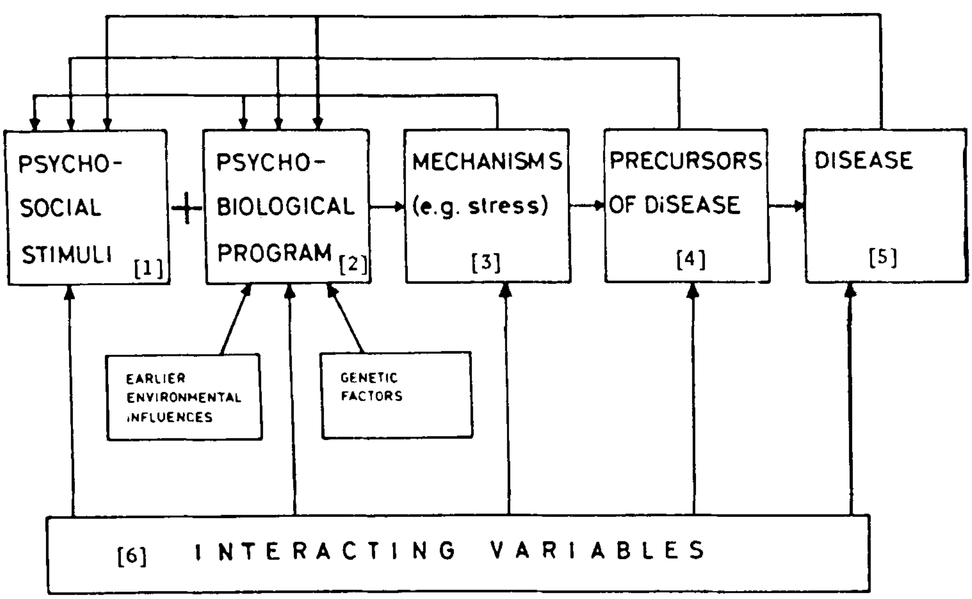

Fig. 3. Selyean stress model for studying the interaction between psychosocial stimuli, stress (as a mechanism leading to disease and disease (modified from Kagan and Levi, 1974).

and across a long period of time.[2] Yet, most diseases, if related to psychosocial factors, are related to chronic problems, and, due to their low incidence, require large samples for analysis. Thus, two issues emerge. One concerns the development of methods for directly linking psychosocial factors to disease. This issue is addressed, albeit not without reservation, by the life-change research. The second concerns the relevance of Selyean stress as the exclusive mechanism by which psychosocial factors cause disease. This remains unresolved and is perhaps the most fundamental issue.

Life change as psychosocial stressor

The delimiting feature of this third theme of stress research is the elimination of measures of Selyean stress and the attempt to directly link psychosocial factors with disease. This type of research is exemplified by the "life-change method" first developed by Holmes and Rahe (1967). The life-change method is based on statistical relationships between "social readjustment scores" and illness. The social readjustment score is computed by first assigning a weight to each life change and then adding the weighted scores for life changes which have occurred during a given unit of time (Holmes and Rahe, 1967). Life-change research focuses on the potential negative consequences of changes in an individual's life. Since life changes are generally easy to identify and are recalled with some degree of reliability, it is not surprising that there has been a proliferation of research on the impact of these changes on health.

While these studies have consistently found positive associations between social readjustment scores and maladies of almost any type, the associations are equally consistently weak, with correlation coefficients typically around .12 (Rabkin and Struening, 1976). As Mechanic (1974) suggests, what is clearly missing from the life-change method is any effort to understand the meaning of events in an individual's life and the importance of intervening factors. Thus, while the life-change method is successful, as evidenced by its continued popularity and ability to provide a statistical linkage between psychosocial factors and disease, it misses too much of the dynamic of this relationship. Furthermore, this research design gives excessive importance to the notion of maintenance of the status quo as most adaptive, an unwarranted assumption for most anthropological studies.

Buffering stress: Social resistance resource

A large and varied set of studies may be considered together in that they address some aspect of the meaning of stressful events for individuals. In the study of social supports, for example, attention is focused on how social and economic resources might buffer the effects of stressful conditions. As social support systems change and vary across groups one can predict that the significance of stressful conditions will similarly change and vary. For example, Berkman and Syme (1979) have examined the increased risk of mortality over a 10-year period for residents of Alameda County, California, in relationship to a crude "network index." Individuals with the fewest network connections have a 1.8–4.6 times increased risk of dying relative to age- and sex-matched peers with the highest number of network connections. Somewhat similarly, Goodman (1984) finds that first-year undergraduates whose social networks do not include one or more fellow students have a two- to threefold increase in days ill.

Unlike life-change research, there is no consistent methodology for measuring social supports. Perhaps the main point of disharmony relates to whether social supports are to be measured based on "perception of support" or by a more "objective" criterion such as the number of network connections. Much of the network methodology frequently used to measure social supports originated in anthropology (Barnes, 1954). Thus, not surprisingly, the study of social supports is beginning to attract cultural anthropologists (Jacobson, 1987). Dressler's (1982; Dressler et al., 1986) work on social supports and blood pressure is particularly relevant.

[2]One of the outstanding problems with hormonal measures of stress, be they based on blood, urine, or salivary samples, is that they "sample" a rather short time frame of endocrinological activation. Catacholamine and corticosteroid turnover is relatively rapid. Thus, chronic activation can only be ascertained by undertaking a rigid, repeat measures sampling strategy with a valid method for calculating mean activation.

Measuring stress in the field

Despite a number of extant problems, stress research is a large and growing field. Why? First, behind all of the problems of measuring perceptions and sociocultural factors is a growing realization of the importance of the social environment in health and adaptation. Thus the main body of stress research has turned from stress physiology and life-change research into what might best be termed sociocultural epidemiology, a field of research with considerable potential for direct linkage to biological anthropology (cf. James et al., 1986). Second, despite the contention that Selyean stress is both hard to measure and unlikely to be the sole mechanism by which sociocultural events translate to disease, it is nontheless both heuristically useful and a likely component mechanism for a variety of ailments. Prior studies of Selyean stress tended to concentrate on rats and humans in contrived situations. Anthropological studies, on the other hand, have focused on stress responses in humans during their daily routine (Brown, 1982; Janes et al., 1986).

The work of Brown (1978, 1981, 1982) represents the pioneering efforts in this area and remains illustrative of the problems and potentials of this method of inquiry. Brown outlines three coping strategies used by Filipino migrants to Oahu, Hawaii. These include 1) the maintenance of native Filipino lifestyle and culture, 2) adoption of an American-urban lifestyle, and 3) efforts both to retain some aspects of the native Filipino culture and lifestyle and to adopt some aspects of the new culture. He then evaluates the relative success of these strategies by comparing mean catecholamine excretion rates based on 24-hour urine collections.

Brown finds that individuals who adopt some elements of the American-urban lifestyle while retaining other elements of Filipino culture excrete the greatest mean quantity of epinephrine and norepinephrine, while those maintaining the Filipino lifestyle excrete the least amount of these catecholamines (1981:82–83). For example, mean epinephrine excretion (in μg/g creatinine) is twice as high in the intermediate group compared to the low-contact group. While these results are highly provocative, they are not statistically significant due mainly to the study's small sample sizes ($n = 16$).

Following Brown, but on a larger scale, Harrison and colleagues at Oxford (Jenner et al., 1982; Reynolds et al., 1981; Summers et al., 1983) have undertaken a multifaceted study of lifestyle and stress in nearby villages. Nearly 900 adults collected early morning, midday, and evening urines on a workday and a rest day, a total of six collections per person. These data, the largest data base of measures of endocrinological stress in free-living humans yet collected, have shown concordance between catecholamines and steroidal measures of stress (17-hydroxycorticosteriods and 17-oxosteroids) and affirmed the role of a variety of lifestyle factors such as work, lack of sleep, coffee consumption, and cigarette smoking in increasing the excretion of these metabolites. In the future these data may be of special use in understanding relationships to biological factors, such as degree of genetic and anthropometric variation in these stress responses. (See Jenner et al., 1982, for interpopulation comparison of catecholamine excretion.)

Somewhat intermediate between the Filipino and Oxfordshire studies are studies of stress in Samoa and among Samoan migrants (Hanna et al., 1986; James, 1984; James et al., 1985; Martz et al., 1984; Sutter, 1980). These studies have been an integral part of a large study of biocultural adaptation of Samoans in the process of migration and "modernization" (Baker et al., 1986) and have been successful in linking lifestyle and hormonal excretion rates. For example, James and co-workers (1985) report on a study of catecholamine excretion in young western Samoan men. They compare the overnight and midmorning catecholamine excretion in groups of rural agriculturists, manual laborers, sedentary workers, and college students. These authors find the lowest epinephrine excretion rates in villagers and laborers and the highest rates in students and sedentary workers. The greatest difference is between students and villagers for midmorning epinephrine (one-tailed $P = .001$). The general concordance between these results and blood-pressure studies suggests that modernization comes with a physiological cost.

The few endocrinological studies of stress in free-living populations have provided some very direct confirmations of the links between physiological stress and broad socioeconomic changes, most notably migration and development. They tell something of the effect of conditions of change on the biology of individuals. These studies do, however, face methodological problems. Urine samples are often difficult to collect; their analysis is time consuming and relatively costly and requires biochemical expertise and equipment. Furthermore, these metabolites are influenced by a wide range of extraneous factors (time, diet, activity level) which may need to be controlled for. Thus, such studies have become impractical for researchers on a tight budget. With advances in analysis of these metabolites (Cook and Beastall, 1987), however, and the possibility of salivary analysis of steroids (Ellison, 1988), some potential for methodological relief is possible.

STRESS IN PREHISTORIC POPULATIONS

Modeling stress in prehistoric populations

Because the degree of stress experienced by individuals long dead cannot be measured by direct physiological methods, the application of a stress model may seem forced. Some may argue that skeletal biologists are attempting to apply models that have limited applicability to past human populations. However, when applied to prehistoric populations a stress model can provide a time depth to the study of adaptation that may not be available from other sources.

Goodman and co-workers (1984a) have presented a model of stress that has been successfully applied to a number of archeological problems. This model (Fig. 2) illustrates the way stressors (insults which can cause physiological disruption) affect the individual's and the population's adaptation. In this model, the environment is the source both of resources necessary for survival and the stressors that adversely affect adaptation. Cultural systems are potentially able to provide critical resources and to buffer individuals from environmental stressors. However, they are not always effective at buffering stress and may produce new threats. If stressors are not buffered, there will be a need to respond on a biological level. Finally, if the physiological response is not adequate, then the population's ability to survive may be challenged.

The consequences of stress experienced by individuals depend on a number of factors such as genetic susceptibility, age, sex, and resiliency. If the individual lacks the reserves necessary to meet challenges, then there is likely to be an increased level of physiological disruption. Furthermore, there is a hierarchical response in how an individual responds to stressors. Soft tissues are generally more rapidly and severily affected by stress than skeletal materials (McCance, 1960; McCance et al., 1961, 1962). Therefore, stress would have to be severe and/or of long duration to cause observable skeletal changes. Even within the skeletal system there is also a hierarchy of response, with, for example, bone being less buffered than teeth (Garn et al., 1965). Finally, while bone and teeth are relatively well protected from stressors, signs of more subtle skeletal and dental disruptions in metabolism may be revealed at a microstructural level (Martin and Armelagos, 1979). Depending on the type of stressor and its strength and duration, adaptive responses may occur at the cellular, tissue, organ, individual, population, or ecological level. While one is able to observe physiological disruptions in bone and teeth at a microstructural level, in studying extinct populations one must be less certain about the importance of these disruptions in terms of functional domains and at a higher level of adaptive consequences.

The skeletal evidence for stress

The response of the human skeleton to stressors is deceptively simple. Osteons (the building blocks of bone) can either be deposited or resorbed, or there can be a response in which both of these processes alternately occur. The skeletal system is responsible for support of the muscles, protecting the vital organs such as the brain and the eyes, producing red blood cells, and maintaining chemical balance in the body. When these functions are disrupted, we find skeletal evidence of stress. While the response is simple, the interpretation of these responses is difficult.

Many diseases leave diagnostic "signatures" on bone. Tuberculosis, syphilis, and leprosy cause skeletal changes which are specific to the pathogen. In leprosy, for example, there are diagnostic resorptive changes in the bones at the base of the nasal cavity and the terminal digits of the hands and feet.

Many pathogens, however, such as staphylococcus and streptococcus, leave only generalized changes in the skeleton. One frequently observes a reaction in the bone periosteum (outer layer) reflecting a pathogenic change that results from an inflammation. The periosteal reaction to inflammations leaves a roughened appearance to the outer layer of bone as the fibrous outer layer is stretched and subperiosteal hemorrhages occur (Steinbock, 1976). Even though it is difficult to determine which pathogen is the cause of the lesion, the occurrence of a periosteal reaction indicates the individual suffered from an infection. Unfortunately, there are pathogens (e.g., many viruses) that do not affect bone. These viruses can cause an illness and even death without any skeletal response.

Nutritional "stressors" are even more difficult to diagnose. The difficulty, in part, centers on previous strategies that attempted to find single cases of well-known deficiences such as rickets and scurvy (Huss-Asmore et al., 1982). While a few mineral and vitamin deficiencies do cause specific skeletal responses that are easily diagnosed, the search for these conditions in prehistory has not been very productive (Huss-Ashmore et al., 1982; Martin et al., 1985). A major breakthrough in analyzing nutritional disease resulted from a movement away from attempting to isolate single nutritional deficiencies to one which focuses on generalized undernutrition (Huss-Ashmore et al., 1982). As single nutritional deficiencies are quite rare, this perspective not only better fits the available materials, but is closer to reality.

With the search for generalized nutritional status has also come a corresponding trend toward the use of multiple indicators, systematically analyzed to provide an understanding of nutritional stress (Huss-Ashmore et al., 1982). For example, there are a number of lesions such as porotic hyperostosis, defects in enamel development, and premature bone loss that, when coupled with evidence of growth retardation, can provide clues to patterns of generalized nutritional deficiency.

In the above we have focused on signs that are most often related to infection and nutrition. Other bone lesions are associated with trauma and degenerative changes. In a sense, studies of prehistoric populations are relatively rich in indicators of stress (Table 1). Some of these indicators point toward specific insults, while others, such as mortality patterns, are of a more general nature.

Prehistoric Nubia: persistent stress in a marginal environment

The pattern of disease in a series of intensive agriculturalists from Sudanese Nubia illustrates the use of the stress model in understanding adaptation in prehistory (Martin et al., 1984). These populations inhabited areas along the west bank of the river Nile opposite the contemporary town of Wadi Halfa from about the time of Christ until A.D.1350. Populations are associated with Meroitic (A.D. 0–A.D. 350)-, X-Group (A.D. 350–A.D. 550)-, and Christian (A.D. 550–A.D. 1350)-period settlements.

While the indicators of stress are diagnosed at the level of the individual, the data may give information on the population's response to the individual's dilemma. For example, an 8-year-old child exhibited a constellation of pathological conditions suggesting that s/he suffered from hydrocephalus severe enough to cause quadriplegia. The disability seriously limited the child's ability to fend for itself. Skeletal analysis suggests that the child had to be carried from place to place and be fed a cereal gruel (as evidenced by the extensive tartar formation on teeth). The survival of the child with such a severe impairment implies that the X-Group society was willing and able to provide the necessary social support to a severely disabled child.

The occurrence of nutritional deficiencies in prehistoric Nubia can be used to illustrate the importance of using multiple stress indicators and analyzing the impact in different adaptive domains. In Nubia, individuals are frequently found to

TABLE 1. Summary of skeletal indicators of stress

Indicators	Parts of the population and skeleton required	Groups at risk	Severity and time of stress	General comments
Life tables and mortality schedules	Large and complete population or representative sample	All	Chronic, severe	Best indicator of overall adaptation. Accuracy of aging technique is critical
Adult stature	Adult population, appendicular skeletons, especially lower extremities	Subadults	Summation of preadult factors	Short stature (small body size) may be a response to chronic undernutrition
Growth curves Retardation Shape differences	Dental-aged subadults and subadult long bones	Subadults	 Chronic Chronic (1 year)	Can aid in estimation of time of greatest stress in an individual's life
Sexual dimorphism	Adult males and females; innominate used primarily, femur and other long bones secondarily	Subadults	Summation of preadult factors	Must consider genetic factors. Sexual dimorphism decreases with increased stress
Harris lines	Adult or subadult radiographs of long bones (tibia, femur and others)	Subadults Adults	Acute stress; reoccurring stress	Some evidence for inverse association with nutritional status; peak occurrence often near weaning
Vertebral canal stenosis	Adult vertebrae	In utero to 3 yr	Early chronic	Unclear association with early deprivations
Skull base height	Adult cranium	In utero to 5 yr	Early chronic	Unclear association with early deprivations
Enamel hypoplasia and enamel microdefects	Any teeth; anteriors more sensitive	0.5 in utero to 7 yr.	Acute stress (w/chronic undernutrition)	Association with nutritional status and decreased longevity; peaks near weaning
Dental asymmetry	Dentition	In utero	Early and severe	Measure of developmental noise. Required sample may be quite large
Dental crowding	Maxilla and mandible with teeth in situ	Subadults	Chronic; severe	May be nutritional, but must not be confused with more common genetic causes
Traumatic lesions	All bones	All	Acute	May differentiate between "violence" and other causes of fractures
Periosteal infection	All ages; long bones	All	Chronic	Some infections may not appear on bone
Porotic hyperostosis and cribra orbitalia	Cranium, particularly orbital regions	Both sexes 0.5–8 yr females 20–30 yr	Acute to severe	Related to iron-deficiency anemia; potential synergism with infection; highest prevalence before 5 yr
Osteoporosis	Femur and rib cross sections commonly used	Juveniles Reproductive females Senile	Acute to severe Chronic to severe Chronic	Evidence for increase in females at reproduction; may be related to calcium or protein-energy malnutrition

be suffering from iron deficiency anemia (as evidenced by the existence of porotoic hyperostosis). To understand the significance of this condition, we have to consider its distribution within the population as indicated by porotoic hyperostosis. Thirty-two percent of the Nubians are iron deficient. An analysis of the condition with regard to age and sex reveals that two segments of the population are at risk—young children (ages 2–6 and young adult females (ages 20–35). This pattern of involvement suggests that diet (reliance on cereal grains), weaning practices, and lactation represent the most likely cause of the iron deficiency.

If these segments of the population are suffering nutritionally, then other biological systems such as long bone growth should show evidence of disruption. Armelagos and co-workers (1972) examined the pattern of long bone growth by looking at length of long bones vs. developmental age. They were not able to detect indisputable evidence of growth disruption. Although individuals were smaller than age-matched peers from a modern American sample, their relative growth velocity was similar to that found in American children.

In order to test for a possibility of growth disruption, the levels of analysis below the individual were investigated. A study of bone at the tissue level showed evidence of a failure to maintain normal skeletal development. Children from their second through their 14th year were not able to maintain normal cortical bone in the walls of the femur. Microscopic analysis (Huss-Ashmore, 1981) suggested that the thin cortices resulted from an increase in intercortical resorption.

In this same population, Martin and Armelagos (1979) showed that young adult women (19–25 years old) also had problems maintaining cortical bone. In the young females, there was a significant increase in rates of endosteal resorption compared to age-matched males. While these women were able to form osteons on their periosteal surface, these osteons were not being mineralized at the rate expected. The resorption of osteons from the periosteal surface apparently was a source for calcium for the lactating women.

An analysis of this problem at an ecological level points toward the diet of the Nubians and exposure to parasites as important causal factors. The reliance on cereal grains, poor sources of iron and calcium, was the most likely cause. While health seems to be perpetually compromised in these populations, Van Gerven and co-workers (1981) have suggested an inverse relationship between levels of political centralization and health. With increased political centralization the lives of prehistoric Nubians, already living in a marginal environment, might be further compromised by loss of political independence and surplus extractions.

This pattern of nutritional stress has been in existence for 4,000 years and may have existed since the Neolithic. Such an example speaks to a broader issue in understanding adaptation. It suggests that a population can survive for a relatively long period even when individuals' health may be compromised.

Stress and economic transition at Dickson Mounds

While the Christian populations in Sudanese Nubia were in the latest phase of their development, populations in the Illinois River Valley were undergoing a significant shift in lifestyle. An analysis of one of these populations, from the Dickson Mounds, provides another example of the use of a stress model. The changes in subsistence from A.D. 950 to A.D. 1300 were profound. In this short period a shift occurred from a Late Woodland adaptation, characterized as a general gathering-hunting strategy, to one which emphasized intensive agriculture, increased population density and sedentarism, and expanded trade networks (Middle Mississippian). The shift in subsistence led to a fourfold increase in iron deficiency anemia (porotic hyperostosis) and a threefold increase in infectious disease (periosteal reaction). The frequency of individuals with both iron deficiency and infectious lesions increased from 6% to 40% by the Middle Mississippian period. Furthermore, individuals with both conditions displayed a synergistic interaction (Lallo et al. 1977, 1978) in which individuals with both lesions showed a more severe manifestation of each condition.

The frequency and chronological distribution of hypoplastic defects of dental enamel in the Dickson Mounds population further support the argument that the shift to agriculture had deleterious effects on the health of the group. There was an increase in hypoplasia from 0.90 defects per individual (Late Woodland) to 1.61 per individual in the Middle Mississippian period (Goodman et al., 1980). The prevalence of individuals with one or more hypoplasias increased from 45% to 80% during the same period (Goodman et al., 1980). Since the chronological development of the enamel is well understood, it is possible to determine the age at which the hypoplasias occurred during the life of the individual. The hypoplastic lines in adults provide a "metabolic memory" of events which occurred during their childhood.

The chronology of enamel hypoplasia shows that the Dickson Mounds population experienced peak stress between the ages of 2 and 4 (Goodman et al., 1984b), which may correspond to the likely age at weaning. The pattern of porotic hyperostosis in this population occurred at about the same phase of development. The comparison of the chronology between the earlier groups and the intensive agriculturalists at Dickson Mounds shows an earlier age of onset of hypoplasia, suggesting an earlier age of weaning.

Enamel hypoplasia is considered a relatively benign defect. However, Goodman and Armelagos (1988) have calculated the mean age at death for those with and without hypoplasias and find startling differences. Individuals with no lesions have a mean age at death 5 years greater than individuals with one hypoplasia and 9 years greater than individuals with two or more hypoplastic episodes. The association between stress during childhood and longevity in adulthood suggests that the stresses producing these insults have significant consequences for the individual's adaptation.

There are at least two hypotheses that have been proposed to explain the differences in mean age at death. The first suggests that those with hypoplasia represent a group of individuals who were poorly buffered from stress due to status differences early in their lifetime and continued to be subjected to insults during the rest of their lives. The second hypothesis suggests that the early stresses leave the individual less able to rally from future insults. While individuals may survive the stress, they are left in a damaged and weakened state. These hypotheses are most readily tested in an historical or contemporary setting.

This economic transition also affected the mortality pattern of the Dickson Mounds population, a final measure of the biological cost of the transition experienced by these populations. Life expectancy decreases at all ages in the later agricultural population (Goodman et al., 1984c).

In summary, the population at Dickson Mounds suffered biologically from its prehistoric transition. The success of the cultural system in capturing more energy through economic intensification occurs at the biological expense of individuals and the population. The ability to reduce birth spacing allowed the population not only to meet the increase in mortality but also to meet the increased labor needs for intensifying agriculture. However, there was an increase in nutritional and infectious disease load which affected all segments of the population, with infants and children at especially great risk.

The adaptive problems faced by the Dickson Mounds population are intriguing. Some of the difficulties are related to their sedentism, which may have contributed to the increase in infectious disease. The increase in the intensification of agriculture and a reliance on maize represent another important factor that may have adversely affected their dietary difficulties. However, another part of the puzzle remains. The Dickson population was in the middle of a very productive ecological zone that could have provided it with the resources necessary to meet its dietary needs. It may be that the population was being exploited by other groups and these important dietary items were being traded to other societies (Goodman et al., 1984c; Goodman and Armelagos, 1985). In a sense, the situation at Dickson may parallel many of the most persistent problems we see today. Due to increased monetization, shifts in markets, and lack of control over pricing, small groups in the sociopolitical hinterlands find themselves unable to meet basic needs they could once meet by reliance on local resources and labor.

Stress and prehistory

The study of Nubian and Dickson Mounds populations attests to the utility of the stress model for our understanding of adaptation in prehistory. The analysis of stressors in prehistoric populations reveals a complex interaction in which there is differential physiological disruption. An understanding of the hierarchical response is valuable in unraveling the success and difficulties that a cultural system, a population, and an individual may have in adjusting to their environment. Important help in interpreting similar problems in historic and contemporary populations is also provided.

The coupling of skeletal biological methods with general principles of stress and adaptation has led prehistorians out of the doldrums of focusing on particular disease episodes. Skeletal biological methods have refocused paleopathologists on the population and the adaptive process. A fuller appreciation of the evolution of stress, however, will force a greater reliance on stress dynamics which are best seen in studies of historical and contemporary populations.

STRESS IN HISTORICAL POPULATIONS

Whereas analysis of skeletal material may extend the study of stress into the distant past, and the analysis of cotemporary populations provides inferences on present-day stressors, historical analysis bridges the two temporally; it also stands midway in regard to the quality of inferences that can be made about stress. Also, as with skeletal biology, there are some legitimate questions concerning the suitability of the stress concept to explain events in the past. The decision to utilize a stress model for historical questions should be based on whether such a model can add to our appreciation of the role of health and disease. It will often be the case that we can infer stress through a dependent variable, such as infant mortality or growth retardation, but not quantify stress itself. Thus, operationally, we may design a satisfactory equation in which stress is not explicitly measured. There are several situations in which human populations find themselves, where a stress model can provide some understanding of the processes involved, even when we cannot precisely measure stress itself. Cases in point are prehistoric or historical cultures undergoing rapid transitions in resource utilization and those in competition with other groups for resources.

The purpose of this section is to outline briefly studies of stress in historical populations. As space is limited, this will be accomplished through the use of a few selected examples. We will discuss a stress process that is measurable by its end result: mortality patterns that are most proximately due to increased nutritional problems and to infectious disease. These latter phenomena are also measures of stress, and are ultimately traced to social conditions. While other indicators of stress are noted, we will focus on infant and early childhood mortality.

Data for the analysis of stress

Historical sources, such as biographies and diaries, are appropriate to use for analysis of psychosocial conditions and perceived stressors. However, as population biologists we tend to emphasize data that are of a demographic, health, anthropometric, or economic nature. In most Western and many non-Western societies appropriate biological and demographic information is abundant in a variety of sources. Written records can be summarized as follows:

1. *Population enumeration*—population censuses, primarily.
2. *Registration of vital events*—civil or church-related recording of births, deaths (often with cause), marriages, and sometimes migration.
3. *Other public records*—tax valuations, occupational listings, hospital records, health reports, public works, military conscription lists, court proceedings, etc.

4. *Private records*—diaries, account books, genealogies, factory records, slave-owner records, and other private papers.

Taken together, these sources can provide a number of relevant variables on the individual, household, group, community, and regional level. Thus, the units of analysis (Swedlund, 1978) are all accessible within the historical context.

Perhaps more so than is the case with skeletal material, we are limited with historical populations in terms of the dependent variable or measure of stress. Most definitively, a mortality event is an indication of stress. Morbidity data can also be found for historical populations, but here again serious questions arise, not the least of which is the quality of the reporting and the problem of reporting errors. While it is not unreasonable to expect a community to keep relatively good track of the number of annual deaths, and to whom they occur, it is quite another to expect an accurate reporting of the number of individuals who contracted, say, measles during that same year. Nevertheless, for parts of historical Europe and North American such data do exist and can, on occasion, be found to be reasonably interpretable.

Other data which have been subjected to analysis that can be reflective of stress include anthropometric data kept by civil or private authorities. Most exemplary of this are the several studies using stature, and sometimes other anthropometric measures, as indicators of nutritional status, standard of living, and health (see, for example, Fogel et al., 1983). This work, which has been done primarily on American and British samples of conscripts or on American slave populations, can often detect remarkably strong associations between famine or overall nutritional changes and secular changes in growth data (Steegman, 1985; Steckel, 1986). There are, however, some caveats to this research (Kunitz, 1987). While we believe these studies demonstrate some of the more interesting and clever applications of historical data to questions of changing health, the remainder of this paper will focus on examples of the use of mortality as an inference concerning stress and adaptation. As both early scholars and contemporary researchers agree, infant mortality constitutes one of the best and most universal indicators of societal well-being available (Haines and Preston, 1984; Swedlund, in press).

Levels of analysis

With historical data we are consequently confined largely to demographic approaches—surely meaningful in terms of consequence, but very crudely and indirectly indicative of stress. If we concern ourselves with the characteristics of populations through which we may be able to detect stressors operating it will be through population 1) growth and size, 2) distribution and density, and 3) composition and diversity. Stress may be measured by events of out-migration and in-migration, by changes in fertility, or by increases in mortality. Since our concern is with mortality we will demonstrate, in examples below, how these data may be associated with growth, density, and composition.

Much of what has been written about the relationship between population and resources and the "stressful" connections between the two can be traced to Malthus. Recall that Malthus theorized that population would grow geometrically as a result of fertility until such a point that resources, in this case food supplies, were exhausted. This would happen, he believed, because the agricultural potential for growth is finite and grows arithmetically. The outcome would be overcrowding, famine, disease, and death—the positive checks. He argued that to avoid these outcomes human populations must reduce marriage and fertility and invoke the preventive check. This theory, problematic though it is, still does inform historical research on the role of mortality. We often expect that to the extent possible, populations will migrate or reduce fertility, and intensify food production to avoid the positive checks (Cohen and Armelagos, 1984). When we do see mortality as a consequence of crowding, nutritional stress, or other such factors then we may have a right to expect that the population is indeed in a stressful situation where alternative responses have failed.

Hollingsworth (1973) and others have noted that when major historical European epidemics are compared, a common sequence of events is seen: population growth in a region is followed by crop failure as a result of climatic conditions or pestilence which, in turn, is followed by famine and ultimately epidemic disease. These conditions were often exacerbated by the inability of the region to import food supplies. Kunitz (1983) has also noted that epidemic disease in Europe was affected significantly by political activities and by troop movements until relatively recent times. These large-scale processes indicate clearly, if somehat imprecisely, the relationship between growth, density, and movement of populations in mortality crises. More apropos of anthropological approaches to these questions, however, is analysis of a smaller region or community. These smaller-scale studies may sacrifice some generality for a more richly detailed and precise assessment of interactions. Such an example can be found in research that has been conducted on communities in the Connecticut River Valley of Massachusetts.

Stress and transitions in the Connecticut River Valley

In contrast to major urban areas, the Connecticut River Valley of Massachusetts of the 18th and 19th centuries never demonstrated excessively high mortality. It did, however, experience some childhood epidemics in the early 19th century and exhibit a gradual increase in infant and childhood mortality during the 1800s (Meindl and Swedlund, 1977; Swedlund et al., 1980; Swedlund, in press). Meanwhile, fertility was actually declining for the native-born population (Temkin-Greener and Swedlund, 1978). We believe these events can be viewed in the context of increasingly stressful conditions on the local populations in question and that compositional factors provide some of the most important insights.

Between the American Revolution and 1900 the Connecticut River Valley witnessed a marked intensification of market agriculture and a transition to an industrial economy with considerable off-farm employment. Significant numbers of foreign-born immigrants moved into the region for employment between 1850 and the end of the century. At least by the time of the Civil War, this region was fully integrated into the national and international economies. These transitions imply several changes in health and provide conditions which in some ways can be considered analogous to more recent industrial development in the Third World.

The rapid transitions experienced by residents of the Connecticut Valley and, indeed, greater New England, were perceived as stressful by large numbers of inhabitants and in some cases were thought overwhelming. Increasing shifts to a market economy with new enterprises and new immigrants caused many to lament the loss of their traditional lifestyle. Religious conservatives and fitness and health reformers who extolled the virtues of a simple, clean life and the "old" ways became increasingly popular. Health complaints, both real and perceived, became epidemic and were blamed on the new order (Nissenbaum, 1980; Whorton, 1982).

The outcome of these various events was increasing population growth, higher population densities, some crowding in manufacturing areas, and less access to or control over food resources, and there is some evidence for nutritional stress. Again, it must be emphasized that these conditions are only relative to previous conditions in the region and do not show the dramatic effects that might be seen in more industrial and urbanized regions of Massachusetts such as Boston, Lowell, or Fall River.

The analysis of patterns of infectious diseases that are sensitive to crowding, contamination, and nutrition should be instructive of changing levels of stress in the population. Two such diseases that are widely acknowledged as being sensitive are tuberculosis and infant diarrhea.

Tuberculosis

The overall mortality rates for tuberculosis show a more or less steady increase from early in the 19th century up to about 1875, with declining rates thereafter. Tuberculosis was one of the major causes of death throughout the period, reaching rates in excess of 35 per 1,000 in 1855 and 1875 (Meindl, 1979). There is at least impressionistic evidence, then, for a positive association between population growth and density and mortality from tuberculosis. Further insights are gained when we look at various groups within the population.

Age. Tuberculosis most significantly affected infants and young children. In fact, rates remained high for infants well after the beginning of the secular decline in mortality. The other group hardest hit consisted of those 60 years of age and over, with the other ages falling well below these two groups. These two groups are, even today, the ones most vulnerable immunologically speaking and are also those who probably have the least access to resources.

Occupation. It is interesting to note that among male farmers mortality from tuberculosis constituted 11% of total mortality, while among unskilled and semiskilled male workers, tuberculosis accounted for almost a quarter (23–24%) of all deaths (McArdle, 1986). This would suggest that the group living in the lowest densities and with the greatest access to food resources is least exposed to this stressor.

Gender. While females have lower mortality rates than males at all ages in developed populations, this has not been true in many historical populations and some less-developed regions today (Nathanson, 1984). One striking finding of earlier research in the Connecticut Valley was that upper-wealth-class girls did not enjoy the same advantages in survivorship that upper-wealth-class boys did relative to their lower-class counterparts (Meindl, 1980). Upon further analysis of this pattern it appears that females at infancy and childhood ages were much more likely to die of tuberculosis than males (Ginsberg and Swedlund, 1986), and this pattern was observed for all of Massachusetts for the late 19th century (Abbott, 1897). The notion that this results from greater susceptibility does not agree with what we know about female constitutions and survivorship in general (Stimson, 1985). Rather, it suggests that on the basis of economic and social evidence, females may have received a lower quality of nutrition and care in this strongly patriarchal society. This may pose a strong case for differential social support affecting mortality by gender (Johansson, 1984).

Class and ethnicity. While we know from previous research that it is the lower-wealth-class children who are most affected by tuberculosis, we are only now beginning a detailed study of these relationships for other age groups. We have documented the fact that during the middle to late 19th century most unskilled and semiskilled workers were also the foreign born. On first inspection of the data it is our impression, and reasonable to assume on the basis of studies in other areas of New England, that tuberculosis was most prevalent among the lower-wealth classes and the foreign born.

Also of interest with respect to the changing pattern of tuberculosis is the principal site of infection for different age groups. Most of the late childhood and adult forms of tuberculosis are clearly respiratory from the diagnoses and descriptions available. However, there is evidence to support significant levels of alimentary tuberculosis in infants and very young children. Furthermore, we should expect this condition to increase with the adoption of artificial feeding of infants which takes place in the late 1800s.

Diarrheal infections

Well documented for this population are a series of childhood epidemics and consistently prevalent cases of diarrheal deaths throughout the 19th century (Meindl and Swedlund, 1977; Meindl, 1979; Swedlund, in press; McArdle, 1986). Infant diarrheas are problematic in terms of their etiolgy and their relationship to nutrition. These cases are, for the most part, expected to be a subset of the general pneumonia-diarrheal complex of bacterial infections, and only on occasion are true cholera or typhoid expected to be the causes. The outcome of a diarrheal infection is in part determined by the health and nutritional status of the infant when attacked; however, there is also evidence that serious cases can contribute to growth stunting (Martorell and Ho, 1984). Moreover, the actual cause of the infection can be an indirect "nutritional" cause, because these cases are most often due to water-borne contamination or contamination of cow's milk or some other food supplement. However, there is no question that many of the cases observed in the Connecticut Valley can be associated with the problems of crowding and, presumably, some nutritional deprivation.

The epidemics typically occur in the late summer or early fall, and while adults may have been infected, the death toll occurs almost exclusively among infants and young children. As one traces the more severe incidents through the 19th century the cases tend to diminish in the more rural and less-industrialized communities and to increase significantly in the industrializing communities, where one finds high-density housing, low incomes, and great opportunities for water contamination. The location and rate of diarrheal diseases in infants and children are strongly associated with the rate of wage-based manufacturing (Ball and Swedlund, 1986). The scenario for the incidence and distribution of this disease in historical New England would not surprise those involved with infant health issues in the contemporary Third World.

Stressed cohorts

One way in which we have attempted to use the notion of stress in a more precise way is to measure the impact of a diarrheal epidemic on an exposed cohort relative to a cohort that did not experience the episode but that is in other ways comparable (Meindl and Swedlund, 1977). Using data from an 1802 epidemic in Greenfield and an 1803 epidemic in Deerfield we observed the casualties and then inquired into the mortality experience of the survivors of these epidemics in relation to their "unstressed" counterparts. The control groups in this case were composed of children born after the epidemic in question and at a time in which they were not exposed to an epidemic during early childhood.

This question was posed with a fitness question in mind, rather than the more "biomedical-anthropological" concerns raised above. We were concerned as to whether the survivors of an epidemic might not be somehow more constitutionally fit than their stricken cohort members, and perhaps even more fit on average than the control group that had not been stricken.

After controlling for age and secular trends we did indeed find that the survivors of epidemics enjoyed, overall, longer average life expectancy than the controls. Their "constitution," whether it was genetic or acquired, seemed to predispose them to relative longevity. We also wanted to know whether or not exposure to the epidemic may have selected for some constitutional or genetic-immune advantage that would also be evidenced in the offspring of survivors. This advantage could be implied by increased longevity or fertility in the children and grandchildren of the original survivors. No evidence could be detected for such an outcome, though small sample sizes were definitely a problem (Meindl, 1984). We note, however, that we should not necessarily expect longevity or fertility differences to occur given the fact that the nonspecific nature of the epidemics themselves was not likely to screen the genotypes effectively. Furthermore, general immune competence might well have related more to adequate nutrition and good health rather than to the possession of particular genotypes in the survivors, as alluded to above.

Nevertheless, we believe that the stressed cohort model is an effective means with which to approach a variety of questions about differential survivorship in many populations. It has been used to some advantage on a historical population in Finland (Mielke et al., 1987) and offers a sound methodological approach regardless of whether the hypothesis about the stress is one of conferring an advantage or one of only conferring another insult on the hosts in question.

Summary: Stress in historical populations

This section illustrates in a limited way the varieties of data and questions that can be approached with historical approaches. It is intended to show that linkages between prehistoric, historical, and contemporary problems and populations are possible and desirable and that stress can be a useful concept in our research. When the concept of stress is coupled with the analysis of populations in transition, we see new opportunities for insights into biocultural and adaptive processes.

STRESS IN CONTEMPORARY POPULATIONS

Although the concept of stress has been formulated from and broadly applied to the study of living populations, most investigations have been conducted over a limited temporal span and concentrate on either soft tissue or physiological phenomena. Consequently, prehistoric and historical approaches provide an invaluable dimension in extending the scope of this concept.

Skeletal biological evidence, for instance, reveals severe and/or long-term disruption of an individual's life and ties this to a proximate causation such as iron deficiency. Inferences as to the environmental and social conditions producing such a cause, however, must remain rather broad. In contrast, the historical demographic approach can yield detailed long-term data on socioeconomic conditions bearing on household and individual stress but has difficulty uncovering the biological responses underlying mortality and morbidity. Clearly, interpretation of these data sets is dependent upon an understanding of biobehavioral dynamics in living populations in order to posit interrelationships between the pieces of information available.

If such an interpretive interchange is to grow, investigations of contemporary human populations need to better integrate the dynamics of stress at two broad levels. The first level shows how stressors affect individual biobehavioral functioning in adaptive domains. The second level builds off from first and is oriented toward how change in functioning affects actual (not potential) behavior at the individual, household, and population level.

Adaptive responses to environmental stressors

While contributions to the study of stress in contemporary groups were reviewed in the beginning of this paper, work carried out over the past 25 years in the high Andes serves to illustrate how these two analytical levels might be integrated. Briefly, the Andes is a region of intense and persistent hypoxic stress accompanied by other significant climatic, biotic, and social stressors. Hence, unpredictable rainfall frequently disrupts agricultural production, and in combination with unequal access to food resources it contributes to widespread undernutrition across the altiplano (Ferroni, 1980).

Furthermore, these multiple stressors undoubtedly operate side by side with perceptual stressors generated by the recent socioeconomic changes and lifestyles in transition. It is expected that all these stressors would concentrate on the poor. These are people who must work harder on less food, who are less protected from both the elements and pathogens because of insufficient access to basic needs, and who perceive a greater loss of control over effective strategies to prevent changes.

While we await studies of endocrinological measures of stress to complement the vivid and abundant ethnographic accounts from Andean peasants on the adverse consequences of change, biological responses to an array of high-altitude stressors have received considerable attention (Baker and Little, 1976; Baker, 1978). Since this work has been well reported, a few summary comments as to its contribution to an integrated understanding of biobehavioral functioning should suffice.

Hypoxia is a constant stressor which, at a given altitude, affects all oxygen-using tissue and for which behavioral buffering responses are generally ineffective. As such, this stressor provides a particularly clear-cut biological example of the stress process from initial effects to long-term consequences. With such pervasive impact on varied organ systems, however, the adaptive interpretation of responses has proven to be inordinately difficult. This is further complicated since many responses alter their form with continuous exposure, either through acclimatization or progressive dysfunction. Also, a beneficial response to hypoxia might complement or interfere with adjustment to another stressor; hence the concept of cross-tolerance or cross-adaptation. Such a realization cautions against facile labeling of individual responses as adaptive without inquiring into their broader systemic consequences.

In an effort to provide a procedure by which relative benefit could be attributed to hypoxic responses, Mazess (1975) introduced the aforementioned concept of adaptive domains. Thus, in order to interpret the larger chest and lung size of the Andean natives as adaptive, rather than dysfunctional or of neutral value, it would be first necessary to demonstrate at the infraindividual level that oxygen supply to the tissue was in fact significantly improved. Following from this, an individual level of confirmation would be sought which demonstrated a positive association between pulmonary function indices and higher-level functioning such as Mazess's work capacity. A final step would be to show how this advantage in working capacity influenced relevant behavior such as food production and could thereby affect survival and reproduction of household members. In essence, Mazess provides a procedure for rigorously evaluating stress responses and consequences which could be applied to other stressors in or beyond the Andes.

Other contributions of Andean high-altitude stress research include studies of developmental acclimatization to hypoxia. These serve to emphasize the importance of early and continuous exposure to stressors in eliciting beneficial responses and contributed immensely to our understanding of human plasticity. As inquiry went beyond hypoxia to include other stressors, the more complicated question of cross-adaptation to a multiple stressor environment was examined. Consideration as to the relative importance of different stressors, in turn, drew attention to the need to describe in more detail their characteristics and potential impacts under actual living conditions. It then became apparent that most high-altitude stressors other than hypoxia were in large part effectively buffered by behavioral responses. In cases such as cold and hypocaloric stressors, biological responses appear to serve as backups to behavioral solutions. While the notion of complementarity between biological and behavioral adaptive responses proved attractive, in some instances it begged the question as to why biological responses were being so heavily relied upon by researchers.

This question was particularly relevant to hypocaloric stress, where slow growth and small body size were shown to conserve energy without apparent dysfunction or reduced productivity (Frisancho et al., 1973; Thomas, 1973). Depending on one's point of view this could be referred to as either an adaptive response or the consequence of growth retardation (see Messer, 1986). Whatever the interpretation, the consistent inability of the elaborate Andean behavioral, technological, and social food acquisition pattern to provide sufficient calories became the focus of inquiry. Given the well-documented Andean postcolonial social history, it can be concluded that this pattern has undergone serious erosion, leaving present populations much more dependent upon their limited biological reserves for solutions. It is with this rather obvious realization that socioeconomic conditions began to compete with environmental stressors as prime factors in explaining Andean human biology.

Thus, the high-altitude research trail has led us to the point where the two predominant themes of stress in the Andes are beginning to merge. The first theme is one of biological and social adaptation to the environment, which emphasizes how people adjust to potentially stressful and marginal conditions. This perspective has been advocated by human biologists and ecologists. The second is a dominant theme of social anthropologists and political economists. It concerns human exploitation or how dominant groups have successfully gained control over Andean resources and labor, subsequently constraining people's efforts to meet their needs. Currently, conditions of economic and political marginality characterize rural highland communities, the adaptive fabric has worn thin, and indicators of biosocial well-being are sending warning signals. Therefore, it may be time to entertain an approach which brings the strengths of these two themes together.

A broader perspective on stress

In moving to a second level of stress dynamics, the individual is placed within a population in the real world. Here, it becomes necessary to probe beyond the linear restrictions of physiological models which isolate single stressors and concentrate primarily on their biological consequences. This is particularly important for stressors such as undernutrition and disease that are influenced by socioeconomic conditions, and where change has the capacity to alter both the intensity of the stressor as well as the response repertoire.

What follows is an example of such change over the past two decades in the high Andean population of Nuñoa, Peru. In building on the investigations of adaptation to specific high-altitude stressors carried out by Baker and colleagues during the 1960's (see Baker and Little, 1976), the present analysis focuses on the consequences of disease. Disease is a state of disrupted biobehavioral function in which the effects of single or multiple stressors (including perceived stressors) have overridden the capacity of the organism to respond effectively. Because such a state not only compromises individual action but can interfere with essential activities of other household and community members, it serves to link biological and social consequences of stress.

This in turn beseeches the investigator to look beyond the confines of the adaptive approach into the social relations and political economic conditions which shape and frequently limit adaptive responses. As has been apparent from the Dickson Mound and Connecticut Valley examples, attention to issues of exploitation and unequal access to resources offers critical insights into the dynamics of stress. The present Andean example illustrates how changes in economic conditions overlie considerations of environmental stress and constrain the behavioral options of small-scale farmers and herders. In this context illness is introduced as a source of increased uncertainty which affects both the production of basic needs and biosocial well-being.

The changes observed in the Nuñoa population fit a general pattern often replicated in small rural communities across the altiplano and throughout many regions in the Third World. This is a pattern of increasing monetization of local resources and human relationships. In the process, resource diversity (e.g., crops and herds) is reduced, basic needs are commercialized, consumption norms increase, and wage labor competes with cooperative activities (Leatherman et al., 1986).

Too frequently loss of resource diversity results in increased vulnerability to environmental and economic perturbation; commercialization of basic needs produces local scarcity necessitating households to generate money for their acquisition; increased consumption norms divert some of this money from the purchase of food and other essentials; and wage labor erodes access to cooperative labor upon which household production is dependent. While some segments of the population benefit from such changes, our concern is with the many who do not. As pointed out for the 19th-century Connecticut Valley, which has distinct parallels to the contemporary Andean condition, class, ethnicity, and gender appear to influence significantly people's options and levels of remuneration under this form of change.

In the case of Nuñoa, significant changes have occurred since the early 1970s accompanying the implementation of agrarian reform measures. Haciendas, which controlled most of the land, were replaced by state-controlled cooperatives. While cooperative members benefited, they composed a relatively small percentage of the total population. Hence in the past 15 years the town population has almost doubled whereas that of the countryside has remained stable (Leatherman et al., 1986).

Access to rural resources (i.e., fuel and fertilizer) has become increasingly problematic not only as a result of greater demand, but because of a tendency of the cooperatives to commercialize products formerly available without cost or obligation. Similarly, home-produced goods such as meat, cheese, and eggs are being marketed out of the hands of Nuñoan residents for prices they cannot afford. This has been facilitated by the proliferation of tiny shops, a Sunday market largely controlled by outsiders, and improved transportation connecting Nunoa to highland cities (Luerssen and Markowitz, 1986).

Commercialization has expanded to affect production as well as consumption. Increasingly wage labor is replacing forms of Andean reciprocity, denying assistance to those who cannot afford it. This is particularly disruptive to Andean subsistence production, which depends on household labor and traditionally has relied upon extrafamilial labor at critical points in the annual cycle (Escobar, 1986). Out-migration of older teenagers and young men to seek employment elsewhere exacerbates the situation. A demographic survey of this population has shown that approximately half of household members are absent from the district, with rates highest in the poorest communities (Carey, 1988). Currently 6- and 7-year-old children are spending over 50% of their time in productive activities, and this rate increases to over 75% for teens (Tucker, 1987). Under such conditions, illness directly affects and diverts labor availability within and beyond the household, and its consequences can be devastating for the small farming family.

Turning to indicators of health, comparisons to previously reported nutritional data indicate that the composition of the diet has changed markedly since the 1960s, especially in the presence of commercial foods (Leonard, 1987). While this has resulted in an increased variety of foods available, for most families nonlocal food is replacing rather than augmenting traditional items. Although the marginal caloric intake of two decades ago has remained the same, newly introduced foods are less nutrient dense than the ones they replaced.

Looking beneath these population dietary data, seasonal fluctuation and socioeconomic differentiation provide important insights into the potential for nutritional stress (Leonard and Thomas, in press). Wealthier households have more diverse diets that are significantly higher in calories with little seasonal change. In contrast, poorer households purchase fewer nonlocal foods and experience marked seasonal fluctuation in caloric intake. Whereas poorer adults consume 1,968 kcal in the postharvest season, an intake comparable to their wealthier counterparts, this falls to 1,388 kcal (−29%) during preharvest when work levels are highest. Results for poorer children reflect a similar trend, suggesting a well-defined hungry period and an inability to gain access to sufficient food.

It should be kept in mind that while the environment can be unpredictable with regard to agricultural production (especially crops), it is hardly impoverished. Truckloads of meat and some of the finest alpaca fiber in the world pass by the doors of the poor on a regular basis. Also, accounts of Andean human ecology are replete with varied strategies for food storage and redistribution. What the current situation of widespread undernutrition suggests is that a large segment of the peasant population has somehow lost control over many of their formerly effective adaptive responses. In the process, the potential stressors of the altiplano have intensified.

In extending this inquiry further, one discovers that children from poorer households in the dietary survey are significantly shorter and lighter than wealthier children. In addition, their stature and weight remain similar to those of children in the population measured 20 years ago (Leonard, 1987). This slow and prolonged growth pattern conforms to that expected from hypocaloric stress (Tanner, 1978) and makes Nunoa children among the shortest of Andean populations (see Greksa, 1986). Although a large anthropometric survey conducted in the 1980s shows adolescents to be growing somewhat more rapidly, the previous growth profile remains intact, providing little evidence for a significant secular change in this population (Leatherman et al., 1985; Carey and Thomas, 1987).

Health status reveals much the same pattern. Whereas improved public health facilities have contributed to a 30% reduction in age-sex-specific mortality rate (21 to 15/1,000) and a 12% reduction in infant mortality rate (146 to 129/1,000) since the 1960s (Carey et al., 1985; Carey and Thomas, 1987), there can be little optimism in contemplating such high values.

Turning to morbidity, a similar pattern to that observed for nutritional status becomes apparent. Illness, however measured, is more prevalent in poorer households. Seasonal surveys revealed that over half the families interviewed had at least one adult member sick at a given time and that this lasted an average of 4–5 days. Illness episodes peaked during the planting and postplanting periods, corresponding with the rainy season, and reached lows during and after the harvest (Leatherman, 1987).

These illnesses resulted in significantly reduced yields per field as well as in fewer fields planted. Whereas wealthier families could compensate for lost labor by hiring individuals to work their fields, for the poor this meant lower levels of production and hence consumption (Leatherman, 1987). Further amplification of this process is provided in a description by Leatherman and co-workers (1986:21). Whether men or women are ill, the care for the sick individual and continuation of household maintenance tasks frequently leads to a reduction in family productive activities. However, when illness threatens to disrupt crucial farming tasks, many individuals choose to continue working, deferring the biological and social costs of sickness until completion of the work. For some this results in extended bed rest and limits their activities in other arenas.

If family and social support ties are sufficiently strong and illness is brief, others help out and the crisis is buffered. Carey has shown that the extensiveness of a household's social support network is associated with lower morbidity among the poor, and especially for single-female-headed households (Carey and Thomas, 1987). For individuals who are strongly linked to the wage labor market (particularly migrants) or who are so chronically ill that they cannot be expected to repay the help of others, extrafamilial assistance can be hard to obtain.

In such cases, the incapacitated family retrenches and plants less, using whatever family labor is available. The most critical cases occur when production is reduced to the point where a farmer continuously fails to grow enough to replenish seed and still contributes to the household food supply. Due to illness and the competing demands of wage labor, the failure of community members to fulfill labor obligations through which they maintain access to communal lands is alarmingly common. As Leatherman and Thomas (1987) note, such retrenchment implies redefining basic needs for the household in a manner which increases the risk of future stress and illness. In this process, production options become progressively more limited, resources become depleted, and ultimately assets such as herds and land are sold. As a final solution, families can migrate either to town or outside the region, but with no assurance that their marginality will be reversed.

Obviously, this process does not affect all households equally. Many elderly who physically can no longer farm, who will not be hired as laborers, and whose children have moved away eke out a meager living even when well (Laliberte-Carey and Tucker, 1986). Likewise, women in their multiple roles as producer, reproducer, and family caretaker appear particularly vulnerable. They represent 80% of the illnesses reported, and problems associated with pre- and postpartum reproduction are responsible for half of the disruption (Leatherman, 1987). Poorer women living in the town of Nuñoa have a shorter postpartum rest period before returning to work, complain of longer after effects, need to supplement breast feeding earlier, and have a higher infant mortality rate than those better off (Iacono and Vitzthum, 1986). Nearly 20% of these women head single-family households. Because most depend on wage labor, which is devalued to approximately half the rate of men's, their position and that of their children, is especially compromised.

In summary we have shown the import of peering beyond the concept of stress as strictly a biological phenomenon in the study of contemporary populations. When this is done contributions leading to an understanding of individual biobehavioral function can be linked to ecological, social, and political-economic factors underlying proximate stressors. In our opinion it is this kind of anthropological integration of the stress process which can provide the most far-reaching insights into how it works, who it affects, and why it not only hovers around the poor but seems to reproduce poverty. Finally, it is the uncovering of these dynamics of stress which can extend this concept's application to historical and prehistorical dimensions.

STRESS, ADAPTATION, AND BIOLOGICAL ANTHROPOLOGY

Is stress a useful construct?

A primary goal of this paper has been to review the development of the concept of stress, first in allied fields and then in biological anthropology, and having done so, to assess the utility of this construct. At first pass and as a theoretical construct, our assessment is that stress is a useful concept for the following reasons.

First, as a higher-level term for the biobehavioral response of organisms to environmental disruptions, stress provides an important albeit challenging level of organization. It is arguable that one does not need this concept: responses could be considered via study of measurable and interpretable phenomena such as demographic and anthropometric characteristics. Stress, however, focuses consideration on 1) the specificity of measures and, most importantly, 2) the relationship between measures. Here, the concept of stress provides a meeting ground for researchers who have traditionally measured phenomena as diverse as life expectancies, weight for age, catecholamine levels, and enamel defects.

Second, the concept of stress focuses attention on the struggle to adjust. Stress, as a mechanism capable of leading to functional impairment and disease (Kagan and Levi, 1974), forces one to consider the biological costs of stressors. The concept of stress redresses an imbalance forced by focusing on adaptation, its sister concept. In studying adaptation we have been dedicated to finding positive and functional responses to environmental constraints. However, it is clear that many constraints, such as persistent poverty, do not initiate adaptive responses. In this sense, stress is an important sort of shadow image of the adaptive process. The difference between the two is only one of focus. While adaptation concentrates on the positive responses to environmental conditions, studying stress forces a consideration of the costs and limits of adaptation.

A preliminary framework

While we see potential theoretical utility in the concept of stress, this does not imply that it has or will be used effectively in biological anthropology. As an evaluative criterion we propose that if this concept is to be adequately analyzed with a wide anthropological lens, then information on the following four components is needed: causation, impact, response, and consequence (see Fig. 4). These four components are briefly outlined below while the following section provides an assessment of current bioanthropological efforts to distinguish these components in studies of prehistoric, historical, and contemporary groups.

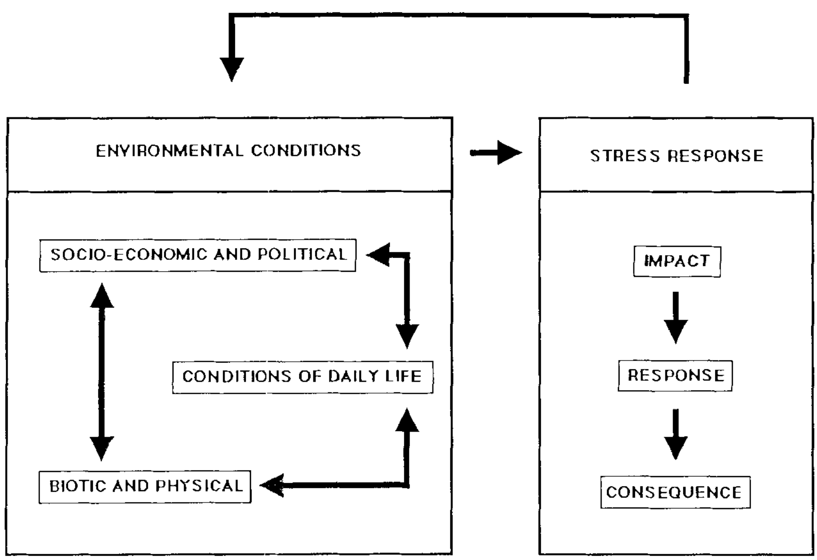

Fig. 4. Model of the stress process, showing the cyclical nature of the relationship between environmental conditions and stress response.

Endeavoring to understand *causation* is first an effort to identify the relevant stressors imposing upon human groups. At one level this may be seen as a rather simplistic effort to measure environmental conditions. However, the case is less clear when one needs to judge which stressors are indeed critical for adaptation. Also, stressors tend to "interact" with each other, sometimes in unpredictable ways, and some stressors may have perceived components, thus entailing analysis of the dialectical nature of individual-environment interactions. Furthermore, and perhaps most importantly, it is easiest to focus on measurement of the proximate or immediate environment. However, the genesis of stress is most often related to long-term processes. Poverty, for example, is a multicomponent stressor which might cause increased perception of vulnerability and increased exposure to "tangible" stressors such as undernutrition, infectious pathogens, and biotic extremes. However, all of these proximate conditions may also be seen as upstream manifestations of sociopolitical and economic processes whose origins might be displaced in both time and space.

Once one has identified the critical stressors and their interactions, then these stressors should be defined not only by relative strength but also by their distribution in time and space. Thus, onset rate, frequency, intensity, duration, distribution, and regularity or predictability become relevant properties of a stressor which affect its impact.

Impact relates to disruption in biobehavioral normalcy for some critical variable. This implies that a physiological strain has been placed on the organism which is capable of disturbing biobehavioral functioning. Clearly an accurate definititon of normalcy is essential for the determination of impact. Given the array of impact measures available (Tables 1, 2), assessment is dependent upon understanding the degree of intra- and interindividual variability for a given indicator. Only when this exists can we make accurate population comparisons. Thus, elevated catecholamine levels, high blood pressure, growth arrest lines, osteoporosis, pneumonia, and mortality constitute indicators which can yield divergent interpretations as to how a given impact might impair biobehavioral functioning.

Response to impact assumes that the organism senses or perceives a deviation from normalcy and initiates actions to cope with this condition. We are interested not only in the effectiveness of these restoring responses but also in how efficiently limited resources (e.g., calories or calcium) are utilized. Effectiveness can be measured in terms of the time it takes to engage in the response, and its duration, strength, rate of action, reliability, and reversibility. Reversibility is a measure of fixity of response once initiated, or alternatively, how difficult it is to disengage. Such a measure becomes relevant in assessing the adaptiveness of a response since irreversible responses may compromise the ability of the organism to respond to subsequent environmental changes. Just as a biological anthropologist may be somewhat overzealous in identifying populations as stressed, attribution of "adaptive" to impact responses has been rather liberally applied (Boyden, 1970).

Consequence refers to the effects of both impacts and responses on the biobehavioral functioning of individuals within populations. Relevant areas of functional assessment include physical performance, nervous system functioning, physical growth and behavioral development, disease resistance, and reproductive performance. These have been referred to us as "adaptive domains" (Mazess, 1975) or "areas of functional competence" (NAS, 1977). As Mezess notes, the interpretation of benefits in any single domain can be temporally, spatially and population specific depending upon patterns of historical exposure to stressors. This includes length of exposure as well as the order and combination of stressors encountered.

Rather than being a list of independent adaptive domains against which to evaluate the relative benefits of responses, it is the interactive effects of these domains on one another which is of primary concern. Thus we are ultimately interested in functional interrelationships such as how lowered immunological competence influences growth and development and in turn affects adult working capacity and/or fertility (see Haas, 1983; and Allen, 1984, for reviews of functional indicators of nutritional status).

TABLE 2. A summary of individual components and measures of stress in living populations (modified from Harrison and Jeffries, 1977)

Components of health and well-being	Indicators	Techniques
Psychological		
1. Satisfaction levels in job, home, etc.	Subjective assessment	Questionnaire, interview
	Use of psychotropic drugs	Questionnaire, interview, medical record
2. Fatigue and sleep patterns	Subjective assessment of fatigue	Questionnaire, interview
	Duration, continuity, & regularity of sleep	Questionnaire, interview, medical record
	Use of sleeping tablets/stimulants	
3. Sensorimotor abilities	Vigilance, reaction times, concentration, manipulatory skills, etc.	Standard psychological performance and vigilance tests
4. Psychiatric status	Evidence of current psychiatric disorders	Psychiatric examination: interview and questionnaire; medical record
	Evidence of past psychiatric disorders	
Physical		
1. Physiological fitness	Work capacity and pulmonary function	Ergometry (VO_2 max.); spirometry (FEV, FVC)
	Muscle strength and physical performance	Dynamometry; performance tasks (Harvard step, etc.)
	Habitual physical activity, energy expenditure	Questionnaire, diary, direct/indirect calorimetry (respirometer/SAMI)
2. Stress reactivity (psychophysiological)	Urinary and salivary catecholamine and corticosteroid levels	High-performance liquid chromatography (HPLC)
		Radioimmunoassay (RIA)
	Blood pressure	Medical examination
3. Nutritional status, growth and physique	Nutrient intake, quality, and quantity	Intake survey, diary, recall questionnaire
	Body build and composition	Anthropometry, photogrammetry
	Sexual maturity, dentition	Puberty rating, dental examination
	Metabolic functions	Urine & blood biochemistry (serum protein, etc.)
	Evidence of deficiencies or excesses	Physical examination (goitre, obesity, rickets, etc.)
4. Infectious disease status	Evidence of current infection	Medical examination, questionnaire, medical record
	Evidence of past infection	
	Immunological status, artificial, natural	Antibody testing, medical record
5. Noninfectious disease status	Evidence of current morbidity	Medical examination (including biochemistry), medical records, questionnaire
	Evidence of past morbidity	
	Inherited defects	Medical examination, cytological tests
	Visual, auditory, olfactory acuity	Tests and physical examination.

Finally, assessment of consequences should not end with these individually oriented areas of biobehavioral functional competence, for they provide few insights into how lifestyle is actually affected. In order to become amenable to anthropological interpretation we will need to know how impairment or improvement influences productive behavior at the individual, household, and population level. What, for example, are the consequences of growth arrest lines, respiratory disease, or lowered working capacity on a critical household member's ability to attain basic needs? At what point does impairment within a number of households compromise the productive capacity and eventually the health status of the entire community?

Unfortunately, many biological anthropologists stop short of providing data on these more socioeconomically oriented questions. By doing so, we leave our data in a form which is inaccessible to most social anthropologists and deny ourselves a glimpse of the real consequences of biological dysfunction. Finally, causation and consequence do not constitute two discrete ends of an elaborate linear progression. Instead, they are more appropriately viewed as a continuum whereby consequences feed back on causation, helping to shape its subsequent characteristics. This is clearly the case in situations of progressive poverty where problems of nutrition and health become intensified with each cycle.

Differentiating impact, response, and consequence

Stress in prehistory

In recent years a variety of skeletal markers of stress have been employed in studying the adaptation of prehistoric populations (Table 1). Due to a limited number of ways in which the skeletal system responds to adverse conditions, we are compromised in our ability to make inferences about specific proximate causes. For example, a variety of nutrient deficiencies and disease states may leave similar markers on skeletal tissues, making it impossible to differentiate the precise cause of a skeletal change. Thus, in skeletal biology the stress concept works at a high level of generalization about cause. This perspective, in which many types of stressors lead to a common stress response, is similar to that of the Selyean stress model. However, the skeletal study of stress differs markedly from Selyean stress in that there is little room for consideration of perceived stress processes.

A challenge to those studying skeletal markers of stress is in differentiating initial impact from response and adaptive consequence. Many skeletal changes may in fact be combinations of these three phenomena. For example, enamel hypoplasias are arguably recording either the impact of metabolic disruptions or the response to these conditions or both impact and response.

Finally, as perhaps with all skeletal markers save for analyses of mortality, there is no clear extrapolation to consequence. Goodman and Armelagos (1988) have recently shown that enamel hypoplasias are associated with decreased longevity in Dickson Mounds populations. Ortner (1989), however, has proposed that these markers are indicative of adaptation or successful rallying from insults. Perhaps the greatest challenge to skeletal biologists is to show the linkage between markers of stress and adaptive consequence.

Stress in historical populations

Differentiating impact from response and consequence on an individual level is also difficult in studies of historical populations. However, historical analyses have the best potential for following these phenomena at higher levels—namely, through families and populations.

In the majority of cases, where all that remains is written records, historical studies may be best able to study consequence. This is exactly opposite the strength of prehistoric studies. In historic studies one can track phenomena such as mortality and examine the effect of changing demographic phenomena on populations. However, because of the lack of availability of biological remains, it is nearly impossible to delineate impact and response. This is then the challenge for historical analyses.

Stress in contemporary populations

While prehistoric-skeletal-based studies are limited in their ability to track consequence, and historical-record-based studies are limited in ability to distinguish impact and response, both of these problems can be overcome in studies of contemporary populations. As is evidenced from the Andean example, it is possible to track the effects of a series of stressors from impact to response and to short-term consequences. While historic and prehistorical studies are needed to trace long-range consequences, details of the process reach their highest resolution in studying contemporary populations. The challenge of contemporary studies is to begin to unravel the relationship among indicators.

Measuring stress: general suggestions

As has been pointed out in the preceding section, each level of analysis entails unique strengths and weaknesses. This variability in character can provide unique complementarity if some commonality in methods is employed. Methods with potential insight into stress which are applicable at two or more levels include 1) mortality and life-table phenomena, 2) anthropometric measures (height and weight being most often recorded), and 3) enamel defects.

Mortality is the ultimate consequence of failure to rally from stressful conditions. One cannot question its meaningfulness. Furthermore, mortality is potentially measurable at all levels of analysis. Unfortunately, mortality is an insensitive, end-stage measure of stress, unable to track more subtle, yet important, transitory changes in small groups.

Nonetheless, mortality, especially infant and early childhood mortality, remains a vital phenomenon to be studied across levels. It is clear that mortality has generally decreased from prehistoric to contemporary populations. Yet the high rates of overall and infant-childhood mortality still found in many parts of the world are reminders that not all populations share in this progress.

Anthropometric measures such as stature of children and adults provide a more sensitive measure of stressful conditions. Anthropometrics constitutes a key method of analysis of nutritional status in living populations (Sutphen, 1985). Similarly, skeletal metrics has been a mainstay of paleodemography and paleopathology (Stini, 1985; Ubelaker, 1978). Anthropometric data are less frequently employed in historical studies, though these data are frequently available and are increasingly viewed as important sources of stress in historical analyses. The most active current "debate" regarding anthropometric measurements concerns their meaningfulness vis-à-vis survival. Currently a variety of studies (such as Bhargava et al., 1978) are beginning to link anthropometric measures with morbidity and mortality. Such studies will not only help to clarify the meaning of anthropometric measures in the contemporary field but will aid in extrapolation to historical and prehistoric studies.

While mortality is an insensitive measure of stress and anthropometric measures record cumulative impact, defects in enamel may provide insights into stresses active during critical stages—for example, present prenatally to early childhood (Rose et al., 1985). Enamel hypoplasias are easily seen on tooth surfaces and have been frequently used to discriminate patterns of stress in prehistoric groups (Goodman et al., 1984b). These defects may also be studied in contemporary marginal populations (Goodman et al., 1987, 1988) and where skeletal materials are available, in historical series (El-Najjar et al., 1978, Goodman, 1988; Mack et al., 1988).

As enamel hypoplasias in permanent teeth of adults and adolescents are retrospective markers of infant-childhood stress, they may provide a time depth to stressful conditions not readily available via other methods in studies of contemporary populations. Furthermore, understanding the relationship between enamel hypoplasias and other stress indicators such as growth, mortality, or even hormonal levels during stressful conditions will help establish the utility of this indicator at all levels of analysis.

Understanding cause

As in the above analysis of the stress response, each level of analysis varies in ability to elucidate causes of stress. In general, skeletal analyses of prehistoric adaptation are best at tracking the effect of general patterns of exposure to traumatic conditions, infectious agents, and nutritional deficiencies. These imporant proximate conditions may in many instances be linked to long-term economic processes such as the change from gathering-hunting to agriculture. In a sense then, prehistoric studies are exemplary for their ability to link proximate factors (exposure to biotic stressors) with broader sociopolitical and economic factors.

Unfortunately the sweep of prehistoric times, combined with a decreased ability to ascertain classes and other groups within populations, decreases one's ability to look inside a stressful process such as the transition to agriculture. Clearly, we can predict that the health changes found in this transition are not evenly distributed either over time or within subgroups. For example, it has been argued on theoretical grounds that this transition would be most stressful at its beginning and would differentially affect infants. While we are beginning to find data, such as patterns of mortality and enamel hypoplasias, confirming that infants were at increased risk, we are only at the beginning of our ability to analyze this process.

Fortunately, the limitations of prehistoric studies are once again the strengths of historical studies. With the ability to link households and families, to study generational effects, to distinguish classes and work groups, and to provide yearly records of events, historical analyses may provide the richest data on the causes of stress. With historical studies middle-level process is most easily tracked.

As is evidenced from the preceding examples, the richest data on the causes of stress may be found in analysis of contemporary populations. The pitfall one most often encounters at this level of analysis is too great a focus on immediate biotic, physical, and social conditions and too little consideration of broader socioeconomic and political process. What is most evident is that we have an opportunity to learn lessons from those who study varying time scales and periods.

CONCLUSIONS: BEYOND THE ADAPTIVIST PERSPECTIVE

By focusing on beneficial responses to stress one frequently omits from analysis broader and highly relevant issues. These issues include socioeconomic conditions which are able to generate, reproduce, and intensify stressful conditions. Conversely, by inquiring into the socioeconomic factors contributing to unequal access to opportunity and resources, the investigator is led to subgroups exposed to the highest levels of insult. Not only are they more exposed to climatic and biological stressors because of an inability to afford the resources that provide protection, but along with these external stressors comes an increased perception of loss of control. Here the two main classes of stressors—perceived and biophysical—converge in a synergistic manner within individuals and households and sometimes even whole communities.

Given such circumstances it is not surprising to find adaptive biological responses intertwined with high rates of morbidity and mortality. What this suggests is that the adaptive behavioral repertoire is exhausted and that "adaptive" biological responses must fill in the gaps. This is why the adaptiveness of small body size is so controversial (Messer, 1986). Saving so many kcal/day by being smaller is of course beneficial for an individual working off marginal intake. The adaptive perspective accepts such marginality as a starting point and inquires about how survival-level biobehavioral functioning is maintained.

There is, however, a related approach which encompasses the adaptive one. This focuses on why social and behavioral responses, which if altered could easily yield the extra calories per day, have become so degraded. It is also an approach which inquires into a level of behavioral and social consequence of stress far beyond individual function. Thus one is better able to see the cyclical interplay between consequence and causation, which for some segments of a population can mean an ongoing process of stress intensification. In essence we are referring to an approach which emphasizes how dominant groups, whether local or external, gain control over the productive behavior of others, and by doing so limit the adaptive options of the subordinate group's behavior.

To many this political economic perspective may seem remote and inappropriate for biological inquiry. We maintain that it is a powerful tool from which to study the biology of poverty and one which complements the adaptive perspective.

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