Patterns of Prehistoric Epidemiology and Human Paleopathology

MAHMOUD Y. EL-NAJJAR, PH.D.

Assistant Professor of Anthropology, New Mexico State University, Las Cruces, New Mexico

Human paleopathologists are interested in the visible marks of diagnosable diseases that reflect various aspects of human biocultural interaction. Whether infectious, nutritional, or a combination of both, pathological characteristics in the dry bone provide some insight into the health of past human populations. Paleoepidemiology and human paleopathology are important parts of ecology in that they deal directly with a major aspect of man's relationship to his environment. The significance of this relationship has, to a large extent, been neglected by human skeletal biologists. The purpose of this study is to examine one of the most important aspects of human biocultural interaction: patterns of nutritional stress.

Materials and Methods

The present study is based on the analysis of 249 human skeletons from the Canyon de Chelly and Canyon del Muerto area in northeastern Arizona. The prehistoric people of Canyon de Chelly are ideal for this type of study. First, they represent an excellent collection of human skeletal remains composed of infants, children, and adults. Second, their cultural history, physical characteristics, biological affinity, and dietary habits have been intensively investigated.[1-4] The inhabitants of these two canyons were the seminomadic hunters and gatherers, "Basket Makers," and their descendant agriculturists, "The Pueblos." These two groups occupied Canyon de Chelly and Canyon del Muerto from AD 100 to AD 1300 when they abandoned their homes and moved south.

Canyon de Chelly and its major tributary Canyon del Muerto occupy an important geographic position serving as a crossroads area in the heart of the Pueblo region. The main canyon, the largest in the Defiance Plateau, has been cut in the western slope by a series of small streams which combine near its head to flow in a westerly direction. The mouth of Canyon de Chelly is on the eastern border of the Chinle Valley and is about 140 miles south-southeast of Mesa Verde, approximately 60 miles from the Utah boundary, and 25 miles east of the New Mexico border. The Chaco Canyon ruins lie about 80 miles to the east and those of San Juan are 60 to 80 miles to the north and northeast.

Age and sex distribution are given in Table 1. Of these skeletons, 182 are stored at the American Museum of Natural History in New York City, 18 at the Field Museum in Chicago, and 49 at the Human Variation Laboratory at Arizona State University, Tempe, Arizona.

Four pathological conditions often used by human paleopathologists as indicators of health conditions were studied: lines and bands of increased density in bone, suggesting growth disturbances; dental wear; the incidence of antemortem tooth loss; and dental caries. In addition, the prevalence of porotic hyperostosis among these canyon inhabitants is reviewed briefly. Lines and bands of increased density were examined using x-ray analysis. All other analyses were done macroscopically.

Presented at the symposium on Paleoepidemiology, 46th Annual Meeting of the American Association of Physical Anthropologists, 14 April, 1977, Seattle, Washington.

Correspondence and reprint requests to Dr. M. Y. El-Najjar, Department of Anthropology, New Mexico State University, Las Cruces, New Mexico, 88003.

TABLE 1
Age and Sex Distribution at Canyon de Chelly

Group	Time period*	Males	Females	Sex unknown	Children	Total
Basket Makers	300– 700	32	45	9	52	138
Pueblos I + II	700–1100	16	9	6	14	45
Pueblo III	900–1300	19	14	9	24	66
Total		67	68	24	90	249

* All dates AD
Note: All percentages have been rounded off to the nearest whole number.

Results

Unlike other parts of the human skeleton, teeth preserve well and often reflect the general health conditions of an individual or a population. Environmental stress in terms of dietary habits, food preparation, and the use of teeth as tools are known to affect tooth structure, health, and survival. Dental wear, antemortem tooth loss, and dental caries leave recognizable structural and pathological defects on the tooth and are examined here.

Dental wear. Among the adult population of Canyon de Chelly, severe dental wear is common. In almost all individuals over 30 years of age, dental wear is so severe that any relevant information on dental crown morphology is impossible.

The wearing away of the tooth surface is a normal result of tooth structure, function, eating habits, and methods of food preparation. The degree of attrition is also determined by the hardness of the teeth, the condition of the supporting bone, the periodontal tissue, and the habits of mastication. In this study, estimates of the degree of dental wear follow the classification of no wear, dentine visible, cusps gone, pulp exposed, and root stumps functional. Tables 2 and 3 present the different degrees of wear in the upper and lower jaws. Among the Basket Maker group, only 7% (4/55) show no wear in the upper jaw and 8% (4/49) in the lower jaw. In the Pueblo group, 9% (2/22) show no wear in the upper jaw and 11% (2/19) in the lower jaw. With two exceptions, none of the differences in the incidence or degree of dental wear between the Basket Maker and Pueblo individuals are statistically significant. This is not unexpected since archaeological and cultural historical data show that their lifestyle and dietary habits did not alter through time. The high degree of severe dental wear is probably the result of eating habits and food preparation. The most common and preferred

TABLE 2
A Comparison of the Various Degrees of Dental Wear Between the Upper and Lower Jaws (Sexes Pooled) of the Basket Makers and Pueblos at Canyon de Chelly

	Upper Jaw		Lower Jaw		
Basket Makers	x/y	%	x/y	%	X^2
0. No wear	4/55	7	4/49	8	0.02
1. Dentine visible	20/55	36	20/49	41	0.23
2. Cusps gone	12/55	22	9/49	18	0.23
3. Pulp exposed	15/55	27	15/49	31	0.15
4. Root stumps functional	4/55	7	1/49	2	1.64
Pueblos					
0. No wear	2/22	9	2/19	11	0.01
1. Dentine visible	6/22	27	3/19	16	0.78
2. Cusps gone	7/22	32	6/19	32	0.00
3. Pulp exposed	4/22	18	5/19	26	0.50
4. Root stumps functional	3/22	14	3/19	16	0.03

x/y = number of individuals showing evidence of dental wear/total number of individuals.
Note: All percentages have been rounded off to the nearest whole number.

TABLE 3
A Comparison of the Degree of Dental Wear Between the Upper and Lower Jaws of the Basket Makers and Pueblos at Canyon de Chelly

	Pueblos		Basket Makers		
	x/y	%	x/y	%	
	Upper Jaw		Upper Jaw		X^2
0. No wear	2/22	9	4/55	7	0.08
1. Dentine visible	6/22	27	20/55	36	0.56
2. Cusps gone	7/22	32	12/55	22	0.88
3. Pulp exposed	4/22	18	15/55	27	0.67
4. Root stumps functional	3/22	14	4/55	7	0.60
	Lower Jaw		Lower Jaw		
0. No wear	2/19	11	4/49	8	0.08
1. Dentine visible	3/19	16	20/49	41	3.85*
2. Cusps gone	6/19	32	9/49	18	1.37
3. Pulp exposed	5/19	26	15/49	31	0.13
4. Root stumps functional	3/19	16	1/49	2	4.82*

x/y = number of individuals showing evidence of dental wear/total number of individuals.
* Significant at the 0.05 level.
Note: All percentages have been rounded off to the nearest whole number.

way of food preparation, especially corn, was by grinding it on a stone metate. This introduced grit and other abrasive material, leading to extreme wear on the teeth of these canyon dwellers.

Antemortem tooth loss. The incidence of antemortem tooth loss among the adult population at Canyon de Chelly is also very high. In the Basket Maker and Pueblo groups over 50% of the individuals have fewer than four teeth in the sockets and over 22% were edentulous. The prevalence and distribution of lost teeth in the various tooth categories is given in Tables 4 and 5. The average incidence of tooth loss is 18% in the upper jaw and 27% in the lower jaw of the Basket Makers, and 16% in the upper jaw and 32% in the lower jaw of the Puebloans. In the upper jaws of the Basket Makers, the lowest incidence of antemortem tooth loss is the right canines (9%) and the highest is in the left second pre-

TABLE 4
Antemortem Tooth Loss in the Upper and Lower Jaws of the Basket Maker Adult Males and Females, Canyon de Chelly

	Upper Jaw		Lower Jaw		
Tooth Group	Number	%	Number	%	X^2
Left central incisors	9/48	19	8/32	25	0.45
Right central incisors	9/47	19	6/32	19	0.01
Left lateral incisors	10/48	21	6/32	19	0.18
Right lateral incisors	7/49	14	7/32	22	0.81
Left canines	7/47	15	7/32	22	0.61
Right canines	4/47	9	5/32	16	1.00
Left first premolars	5/48	10	9/32	28	4.15*
Right first premolars	7/49	14	8/32	25	1.45
Left second premolars	11/48	23	12/32	38	1.97
Right second premolars	7/49	14	7/32	22	0.83
Left first molars	11/48	23	12/32	38	1.97
Right first molars	11/49	22	10/32	31	0.74
Left second molars	11/48	23	12/32	38	1.97
Right second molars	11/49	22	13/32	41	3.02

* Significant at the 0.05 level.
Note: All percentages have been rounded off to the nearest whole number.

TABLE 5
Antemortem Tooth Loss in the Upper and Lower Jaws of the Pueblo Adult Males and Females, Canyon de Chelly.

Tooth Group	Upper Jaw		Lower Jaw		
	Number	%	Number	%	X^2
Left central incisors	5/38	13	3/26	12	0.03
Right central incisors	3/38	8	3/26	12	0.24
Left lateral incisors	4/39	10	2/25	8	0.24
Right lateral incisors	5/38	13	4/25	16	0.10
Left canines	3/39	8	2/25	8	0.02
Right canines	2/38	5	3/25	12	0.89
Left first premolars	4/40	10	6/25	24	2.37
Right first premolars	4/39	10	7/25	28	3.34
Left second premolars	7/40	18	11/25	44	5.45*
Right second premolars	7/39	18	10/25	40	3.75
Left first molars	11/40	28	15/25	60	6.76
Right first molars	13/40	33	14/25	56	3.45
Left second molars	9/40	23	15/25	60	9.36**
Right second molars	11/40	28	16/25	64	8.37**

* Significant at the 0.05 level.
** Significant at the 0.01 level.
Note: All percentages have been rounded off to the nearest whole number.

molars, left first, and left second molars (23%). Only the left first premolars show significant differences in the incidence of antemortem tooth loss between the upper and lower jaws of the Basket Maker group.

Among Puebloans, the lowest incidence of tooth loss (5%) is in the right upper canines and the highest (33%) is in the upper first molars. In the lower jaw, the lowest incidence is in the left lateral incisors and in the left canines (8%) and the highest is in the right second molars (64%). In comparing the upper and lower jaws of the Puebloans, the differences in only three tooth groups, left second premolars, left first molars, and left and right second molars, are significant at the 0.05 and 0.01 levels respectively. The average incidence of antemortem tooth loss of the upper and lower jaws of the Basket Maker and Pueblo groups were also compared. Chi-square values of 0.54 and 1.75 for the upper and lower jaws respectively were nonsignificant.

Tooth loss has been attributed to periodontal diseases as well as nutritional deficiences. Shaw[1] finds acute protein deprivation in albino rats to cause degeneration of the connective tissue components of the gingiva and the periodontal membrane, osteoporosis of the alveolar bone, and retardation in the formation of the cementum. Kerr[2] indicates that vitamin C deficiency enhances gingival bleeding due to local factors because of the altered capillary permeability. It also prevents repair of the periosteum in the face of chronic destructive periodontal disease, so that the disease may progress more rapidly in the individual with the vitamin deficiency. The higher incidence of tooth loss among these canyon dwellers than elsewhere in the American Southwest appears to be related to some form of nutritional stress, dental diseases due to lack of personal hygiene, eating habits, and the use of teeth as tools in basket-making.

Dental caries. Unlike severe dental wear and high incidence of antemortem tooth loss, the incidence of dental caries among the Canyon de Chelly people is comparatively low. Only 15% (8/55) of the adult Basket Maker individuals have one or more carious teeth in the upper jaw and 31% (15/49) in the lower jaw. Among Puebloans, 14% (3/22) have one or more carious teeth in the upper jaw and 26% (5/19) in the lower jaw. The differences in the incidence of dental caries between the Basket Makers and Puebloans are nonsignificant.

The incidence of dental caries among other Southwestern Puebloans is much higher. Hooton,[3] in his study of the Indians of Pecos Pueblo, New Mexico, reports dental caries in 46% of the males and in 49% of the females. The incidence, according to Hooton, increases from prehistoric to historic times. C. Swanson reports (written communication, June, 1976) an even higher incidence of dental caries among the Gran Quivira Pueblo Indians, New Mexico. The Spanish established a mission at Gran Quiv-

ira and for over a century the inhabitants suffered a great deal from malnutrition, diseases, and epidemics introduced by the settlers. Neumann and Disalvo[4] found dental caries to be low among Indians on their native diets, but on the increase with the adoption of modern diets which are higher in carbohydrates and are inadequate from the viewpoint of balanced nutrition.

Discussion

Although emphasis on different food items may have changed during the 1,000 years of occupation of Canyon de Chelly, there appears to be no major shift(s) in essential dietary constituents. Throughout this period, the dietary emphasis remained on corn, beans, and squash.[5] During the period between AD 200 and AD 700, environmental conditions necessary for successful cultivation of corn, such as availability of soil moisture when the soils are sufficiently warm for germination, abundance and frequency of rain during the growth and filling periods, and the date of the first killing frost, existed as they do today.[6] The most important change between AD 700 and AD 1000, was the introduction of a new variety of corn which was larger, of a high yield per plant, and more drought-resistant. This variety made smaller plots more productive and corn could be grown under more diverse conditions.[6] Wild plants, such as cactus pods, fruits, amaranth, chenopods, and piñon nuts, all of which grow abundantly in the Canyon de Chelly area today, may also have been used for food.

For the prehistoric infants at Canyon de Chelly, breast milk provided an adequate food source even under conditions where diet and sanitary facilities were serious health hazards. During the early months of infancy, milk provides a balanced and nutritious diet. If lactation is prolonged beyond six months of age, then supplementary foods must be added. Once these infants were weaned, the introduction of foods other than breast milk may have led to various types of health-related problems. The family diet may have lacked the sanitary conditions provided by breast milk and the adult diet may not have contained the essential nutrients which are much more critical for the growing child.

At Canyon de Chelly, environmental conditions (communal living during the intensive farming Pueblo period, water and food contamination, and the lack of sanitary facilities) were such that a variety of infectious agents were easily introduced, in particular, those pathogens related to gastrointestinal disorders. The domestication of the turkey introduced an additional variety of disease vectors. Turkey domestication has been associated with salmonella which can cause diarrhea. For these weanlings, morbidity and mortality would be at a maximum. Of the 249 human skeletons recovered from the Canyon de Chelly area, 23% (56) were of children under three years of age. Colton[7] reports that epidemics brought about by lack of sanitary facilities caused decimation of whole Pueblo groups in prehistoric and historic times. Among contemporary Pueblos, infectious diarrhea is still the major health problem and the cause of high rates of infant mortality. Significant differences in infant morbidity and mortality within the same Pueblo village, depending on the availability of running water in the inhabitants' homes, has been reported by Sievers[8] and Rubenstein et al.[9]

The adjustment of infants to the adult diet, often lacking the necessary requirements of iron and protein, was another health problem. For example, in spite of the low biological value and concentration of proteins and iron in corn, adults can normally satisfy their nutritional needs if enough corn is consumed. For children, however, the situation is different. An infant or young child would have to consume 450 gm of corn or about 800 gm of tortilla to satisfy its daily protein requirements. Not only is this physically impossible,[10] but the child would consume more calories than it needs. This shift from breast-feeding to an iron- and protein-deficient diet at a time when the need for these nutrients is at its maximum may have further lowered these children's resistance to other childhood diseases. Jelliffe[11] reports, for example, that individuals with protein-deficient diets have a lower resistance to disease.

These factors are reflected in the bands of increased density found during the period of bone growth in a sample of 36 femora from 20 individuals radiographed. The combined count of lines-plus-remnants was 1.8 per femur. This incidence is high. That these lines and bands are associated with disease episodes, particularly during childhood, has been suggested by several authors.[12-14] Caffey[15] reports that Harris lines are formed as a result of growth disturbance due to metabolic insults, especially starvation and fever. Park et al[16] and Garn et al[17] suggest that these lines may be the result of a disease, the consequence of therapy, or may result from the ingestion of heavy metals such as bismuth and lead; however, as these lines do resorb, it is difficult to relate them to any specific etiology. Schwager,[18] for example, has

shown that a new line may appear even though no disease was reported in the previous six months. Gray[19] has also indicated that the presence of lines in an adult population does not conclusively point to a rugged childhood.

Recent longitudinal study by Garn et al[17] at the Fels Research Institute has demonstrated a significant correlation between certain disease episodes and the appearance of new lines. Whooping cough, chickenpox, pneumonia, smallpox immunization, and minor surgery such as tonsillectomy and adenoidectomy were all associated with line formation. McHenry,[20] examining California Indians, also reports that lines and bands of increased density form as a result of starvation and disease, and therefore, their incidence should reflect nutritional and/or the disease status of the population.

The distribution of porotic hyperostosis (Table 6), a pathological condition resulting from bone marrow hyperplasia, provides additional evidence to the probable cause(s) of the high rates of infant mortality at Canyon de Chelly. It has been shown[5,21–23] that porotic hyperostosis among Southwestern American Indians inhabiting canyon bottoms was due to nutritional anemia, possibly a combination of iron and protein deficiencies. Porotic hyperostosis reaches an unusually high incidence of 88% among the Canyon de Chelly Pueblo children where these two items are known to be lacking. In neighboring sage plains areas where the diet contained ample iron and protein, the incidence is only 18%.

Conclusion

The type and degree of pathological manifestations in the skeletons of the Canyon de Chelly people show signs of environmental stress. The high rates of infant mortality and morbidity appear to be the result of inadequate nutrition during the critical periods of growth. Poor sanitary conditions further lessened these children's resistance to common childhood diseases, making them easy prey to disease epidemics. The adult population, however, does not appear to be unhealthy. It cannot be precisely documented how dietary habits affected the dental health of the adult population. Limited food varieties, food preparation, mastication of plant roots, and other stresses imposed by the environment, all undoubtedly contributed to the prevalence of dental wear and antemortem tooth loss. This suggests a rapid effect of tooth-destructive forces, which can be viewed as more critical here than elsewhere in the American Southwest. Tooth retention has adaptive value, and from this study a picture of heavy stress seems to emerge for these canyon dwellers. From the existing data it can only be suggested that the canyon habitat seems to have adversely affected tooth survival, possibly due to the inhabitants' over-dependency on cariogenic maize as well as a diet generally lacking in roughage and animal protein.

TABLE 6
Geographic, Age and Sex Distribution of Porotic Hyperostosis

	Number with PH/total number		Number with PH/total number		X^2
1. Geographic distribution	Canyon sites		Sage plains sites		
Total	54%	146/270	15%	39/269	93.5*
Children	76%	68/90	17%	19/110	68.4*
2. Age distribution	Children		Adults		
Canyon sites	76%	68/90	43%	78/180	25.0*
Sage plains	17%	19/110	13%	20/159	1.19
3. Sex distribution	Males		Females		
Canyon sites	37%	31/84	49%	47/96	2.65
Sage plains	13%	10/75	12%	10/84	0.08

* All values are highly significant.
Canyon sites = Canyon de Chelly, Chaco Canyon, Inscription House, Arizona
Sage plains sites = Gran Quivira, Navajo Reservoir district, New Mexico
Note: All percentages have been rounded off to the nearest whole number.

REFERENCES

1. SHAW JH: The relation of nutrition to periodontal diseases. *J Dent Res* 41:264–271, 1962.

2. KERR DA: Relations between periodontal diseases and systemic diseases. *J Dent Res* 41:302–304, 1962.

3. HOOTON EA: *The Indians of Pecos Pueblo. A Study of Their Skeletal Remains.* New Haven, Yale University Press, 1930.

4. NEUMANN HH, DISALVO NA: Caries concept and caries epidemiology. *J Indiana Dent Assoc* 38:354, 1959.

5. EL-NAJJAR MY: *People of Canyon de Chelly. A Study of Their Biology and Culture,* thesis. Arizona State University, Tempe, 1974.

6. SCHOENWETTER J, DITTERT AE: *An Ecological Interpretation of Anasazi Settlement Pattern.* Anthropological Archaeology in the Americas. The Anthropological Society of Washington, 1968.

7. COLTON HS: The rise and fall of the prehistoric population of Northern Arizona. *Science* 84:337–343, 1936.

8. SIEVERS ML: Disease patterns among Southwestern Indians. *Pub Health Rep* 81:1075–1083, 1966.

9. RUBENSTEIN A, BOYLE J, ODOROFF CL, ET AL: Effect of improved sanitary facilities on infant diarrhea in a Hopi village. *Pub Health Rep* 84:1093–1097, 1969.

10. BEHAR M: Food and nutrition of the Maya before the conquest and at the present time, in *Biomedical Challenges Presented by the American Indians,* publication 165. Pan American Health Organization, 1968, pp 114–119.

11. JELLIFFE DB: Protein calorie malnutrition in tropical preschool children. *J Pediatr* 54:227–256, 1959.

12. ACHESON RM: Effects of starvation, septicemia, and chronic illness on the growth cartilage plate and metaphysis of the immature rat. *J Anat* 93:123–130, 1959.

13. WELLS C: Les lignes de Harris et les maladies anciennes. *Scalpel* 117:665–671, 1964.

14. HARRIS HA: The growth of the long bones in childhood, with special reference to bony striations of the metaphysis and to the role of vitamins. *Arch Int Med* 38:785–806, 1926.

15. CAFFEY J: Transverse lines, in *Pediatric X-Ray Diagnosis.* Yearbook Publishers Inc, 1961, pp 851–858.

16. PARK EA, JACKSON D, GOODWIN TC, ET AL: X-ray shadows in growing bones produced by lead; their characteristics, cause, anatomical counterpart in bone and differentiation. *J Pediatr* 3:265–298, 1933.

17. GARN SM, SILVERMAN FN, HERTZOG KP, ET AL: Lines and bands of increased density. *Med Radiol Photogr* 44:58–89, 1968.

18. SCHWAGER PM: The frequency of appearance of transverse lines in the tibia in relation to childhood illness. *Am J Phys Anthropol* 29:130, 1968.

19. GRAY PHK: Radiography of ancient Egyptian mummies. *Med Radiogr Photogr* 43:34–44, 1967.

20. MCHENRY H: Transverse lines in long bones of prehistoric California Indians. *Am J Phys Anthropol* 29:1–17, 1968.

21. EL-NAJJAR MY, LOZOF B, RYAN DJ: The paleoepidemiology of porotic hyperostosis in the American Southwest: Radiographical and ecological considerations. *Am J Roentgenol Radium Ther Nucl Med* 125:918–925, 1975.

22. EL-NAJJAR MY, RYAN DJ, TURNER CG, ET AL: The etiology of porotic hyperostosis among the prehistoric and historic Anasazi Indians of Southwestern United States. *Am J Phys Anthropol* 44:477–488, 1976.

23. EL-NAJJAR MY, ROBERTSON A: Spongy bones in prehistoric America. *Science* 193:141–143, 1976.