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HELMINTH REMAINS FROM PREHISTORIC INDIAN COPROLITES ON THE COLORADO PLATEAU

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ABSTRACT: Examination of coprolites excavated from archaeological sites in the Americas demonstrates excellent preservation of helminth eggs and, in some cases, larvae. To gain an understanding of helminth parasitism in prehistory on the Colorado Plateau of Arizona, New Mexico, and Utah, 319 coprolites from 5 archaeological sites were analyzed. Helminth eggs and larvae were recovered after the coprolites were rehydrated, screened, and sedimented. At a sixth site, soils excavated from 5 rooms used as latrine areas were processed with palynological techniques. The results indicate that all but 1 of the prehistoric populations examined were infected with intestinal worms. The helminths implicated are *Enterobius vermicularis*, *Trichuris trichiura*, cf. *Ascaris lumbricoides*, cf. *Trichostrongylus* sp., cf. *Strongyloides* sp., taeniid cestodes, and hymenolepidid cestodes. The study suggests that prehistoric hunter-gatherer peoples carried fewer helminth parasites than agriculturalists. At 1 site, it appears that increased helminth parasitism preceded abandonment of the village.

Helminthological research with desiccated feces (coprolites) has a 30-yr history in the Americas beginning with analysis of Peruvian coprolites by Callen and Cameron (Horne, 1985). Such research has intensified in the last decade, especially in Brazil (Ferreira et al., 1980, 1983, 1984; Araujo et al., 1981, 1982, 1983, 1985; Confalonieri et al., 1981, 1985), Peru (Patrucco et al., 1983; Weir and Bonavia, 1985), and the southwestern United States (Fry and Hall, 1975; Fry, 1977, 1980; Stiger, 1977; Hevly et al., 1979; Reinhard, 1985a, 1985b, 1985c; Reinhard et al., 1985) where coprolites are most often found. The emerging field of "paleoparasitology" can be traced as a development of paleopathology, the study of prehistoric diseases (Araujo et al., 1981).

In North America, some of the first analyses were done in the Great Basin of Nevada and northwestern Utah (Fig. 1). Fascioloid eggs were found in a human coprolite from Lovelock Cave, Nevada (Heizer and Napton, 1965). Eggs of probably *Moniliformis clarki*, *Enterobius vermicularis*, and taeniid cestodes were found in Danger and Hogup caves in Utah (Fry and Hall, 1969; Fry and Moore, 1969; Moore et al., 1969). Studies have extended eastward and southward to include the Sonoran Desert (Reinhard and Hevly, 1984) and Hinds Cave in the Chihuahuan Desert of Texas (Bryant and Williams-Dean, 1975).

On the Colorado Plateau of the southwestern United States there is evidence of prehistoric in-

fection with *E. vermicularis* (Samuels, 1965; Fry and Hall, 1969, 1975; Hall, 1972; Fry, 1977; Stiger, 1977), taeniid cestodes (Fry, 1977), possibly *Strongyloides stercoralis* (Hall, 1972; Fry, 1980), *Moniliformis clarki* (Fry and Hall, 1969; Moore et al., 1969; Fry, 1977), unidentified trematode species (Moore et al., 1974), and an unidentified acanthocephalan species (Hall, 1972; Fry, 1980). These finds have been made at several sites in Mesa Verde National Park, Colorado, Glen Canyon and Clyde's Cavern, Utah, Antelope House at Canyon de Chelly National Monument, and at Inscription House, Navajo Monument, Arizona (Fig. 1). Coprolites from sites attributed to the prehistoric Anasazi culture are most frequently studied.

The report presented below, of analyses of coprolites from the Colorado Plateau, doubles the total number of coprolites that have been analyzed for helminth remains from the western states. The coprolite samples represent both prehistoric hunter-gatherers and agriculturalists. The analyses constitute a significant contribution to our knowledge of parasitism in the prehistory of the American Southwest.

MATERIALS AND METHODS

Three hundred nineteen coprolites, as well as soil samples, were examined from 6 sites (Fig. 1). Three sites were located in caves. Dust Devil Cave was sporadically used by small, nomadic, hunter-gatherer bands from 8,800 yr ago to 6,800 yr ago (Reinhard et al., 1985). One hundred coprolites were analyzed from Dust Devil Cave. Twenty-five coprolites were analyzed from Turkey Pen Cave, which was used by Anasazi agriculturalists approximately 1,600 yr ago. Both caves are located in the extreme southeastern portion of Utah. The third cave, Antelope House in Canyon de Chelly National Monument, Arizona, was utilized by Anasazi

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FIGURE 1. Localities in the southwestern United States where helminth remains have been recovered from prehistoric fecal deposits.

agriculturalists from A.D. 200 to A.D. 1250. Sixty-two coprolites from Antelope House dating between A.D. 1175 and A.D. 1250 were examined.

At Salmon Ruin, located 14 miles east of Farmington, New Mexico, latrine areas were found in some rooms. The site was built in A.D. 1088 by the Anasazi and burned at approximately A.D. 1275. Coprolites in 1 latrine area were preserved by the deep covering (approximately 3 m) of rubble and charcoal resulting from the fire. Of several thousand coprolites available for study, 112 dating between A.D. 1200 and 1275 were selected for analysis. Twenty coprolites dating between A.D. 1150 and 1200 were analyzed from the sites of Pueblo Bonito, Pueblo Alto, and Kin Kletso in Chaco Canyon National Monument, New Mexico.

The value of studying archaeological latrine soils for helminth remains has been repeatedly demonstrated (Taylor, 1955; Pike, 1967, 1975; Moore, 1981; Gooch, 1983; Jones, 1985; Hermann, 1986; Reinhard et al., 1986). In the excavation of Elden Pueblo near Flagstaff, Arizona, soils were found in 5 rooms used as latrines between A.D. 1070 and 1250. These fecal deposits were up to 60 cm deep.

For the purposes of helminthological study, only 0.5-g samples were rehydrated from each coprolite. Before the samples were taken, the coprolites were examined for evidence of bore holes through which nematodes from the surrounding environment may have entered the feces. All coprolites were rehydrated in a 0.5% tri-

sodium phosphate solution. To ensure rehydration, the coprolites were completely immersed in the solution for a minimum of 48 hr and a maximum of 72 hr. After 24 hr, acetic formalin alcohol was added to each rehydrating coprolite to retard fungal and bacterial decomposition. Disaggregation of the rehydrated coprolites was usually accomplished by washing the material with a jet of distilled water. In many cases, high fiber content of the feces impaired disaggregation. In these cases, the feces were disaggregated with a magnetic stirrer. After disaggregation, the feces were screened with distilled water through 0.95-mm and 0.5-mm screens. The fluid that passed through the screens was centrifuged to concentrate microscopic remains containing helminth eggs. The microscopic remains were transferred to vials in acetic formalin alcohol and allowed to settle. After sedimentation, the upper levels of the remains were pipetted onto microscopic slides, mounted in glycerol, and scanned for the presence of eggs or larvae. Three preparations were made from each coprolite.

Soils from Elden Pueblo were processed through palynological extraction procedures (Hevly et al., 1979). The process consists of sequential baths of hydrochloric acid, hydrofluoric acid, acetic acid, acetolysis solution (9 parts acetic anhydride to 1 part sulfuric acid), and potassium hydroxide.

Clinical techniques were applied to the rehydrated coprolites after Fry (1977). In the case of the coprolites

FIGURE 2. *Enterobius vermicularis* has been recovered from several sites in good preservation (a, b). Hymenolepidid eggs were found in coprolites from Antelope House (c, d). Bar = 20 μ m.

discussed here, zinc sulfate flotation and formalin-ether separation techniques proved ineffective.

RESULTS

In coprolites from cave sites, bore holes were rarely found. Coprolites from the open sites of Salmon Ruin and Chaco Canyon showed extensive nematode and arthropod activity. It is important to be aware of the possible presence of free-living nematodes when examining feces for nematode larvae. This aids in the determination of whether larvae are of probable parasitic origin

or simply free-living animals (Samuels, 1965; Reinhard, 1985a, 1985b).

Although 100 human feces were analyzed from Dust Devil Cave, none were found to contain helminth remains. Dietary studies indicates that the inhabitants of the cave were nomadic hunters and gatherers (Reinhard et al., 1985). The coprolites were found in a circumscribed area of the cave showing that a rudimentary system for feces disposal was established by these hunter-gatherers.

Of 25 feces from Turkey Pen Cave, 24 were

FIGURE 3. What are probably *Strongyloides* larvae (a, c) and *Trichostrongylus* eggs (b, d) were found in coprolites from Antelope House. Bar = 50 μ m.

FIGURE 4. Helminth eggs recorded from palynological extraction of latrine soils from Elden Pueblo included *Ascaris lumbricoides* (a), *Trichuris trichiura* (b), *Enterobius vermicularis* (c), and taeniid cestodes (d). Bar = 20 μm .

of human origin and 1 was from a dog. Of the 24 human coprolites, 7 contained eggs of *Enterobius vermicularis* (Fig. 2). Dietary evidence demonstrates that the inhabitants of Turkey Pen were agriculturists who also foraged for wild plant foods.

Dietary analysis of coprolites from Antelope House shows that the population subsisted on corn agriculture and on the collection of food plants from riverine areas. Coprolites were randomly deposited throughout the site, showing no plan for excreta disposal.

Of the 62 feces examined from Antelope House, 13 were from dogs. First-stage rhabditiform larvae were found in 2 dog coprolites (Fig. 3). Similar larvae were found in 1 human coprolite. The morphology of these larvae is consistent with that of *Strongyloides* (Reinhard, 1985c). Because only first-stage larvae are present in the coprolites, and there is no evidence of free-living nematode penetration from the cave environment, we feel that these larvae are probably those of *Strongyloides* sp., although there is the possibility that the larvae may be free-living. A total of 538 larvae were examined from the coprolites. The larvae ranged in length from 260 to 360 μm and the average length was 270 μm . The larvae have a short, tapered tail (Fig. 3). A well-defined intestine runs approximately $\frac{2}{3}$ the length of the larvae.

One human coprolite contained eggs of *E. vermicularis* and probably *Trichostrongylus* sp. (Fig. 3). Measurements of 44 well-preserved *Trichostrongylus* eggs were taken. They are ovoid and average 78 by 45 μm , are thin-walled, and contain well-preserved larvae. Because of the similarity in shape between ancyllostomid eggs and *Trichostrongylus*, the identification of *Trichostrongylus* sp. is tentative. *Enterobius vermicularis* eggs were found in 8 other human feces.

Cestode ova were found in another Antelope House human specimen (Fig. 2). These eggs appear to be decorticated hymenolepidid eggs and average 30 μm in diameter. Hooklets on the oncosphere are approximately 8–10 μm in length.

Both Salmon Ruin and the Chaco Canyon villages were agricultural. Dietary analysis of Salmon Ruin was hampered by partial decomposition of most coprolites. The surviving evidence and studies of subsistence materials not found with coprolites (Adams, 1980; Doebly, 1981) indicate that the people inhabiting Salmon Ruin carried out corn agriculture and also foraged in the xeric pinyon-juniper woodland surrounding the site.

Several latrine areas were found within the site. Of 112 coprolites examined, 9 contained eggs of *E. vermicularis*. Of 20 coprolites from Chaco Canyon, 2 contained *E. vermicularis* eggs (Fig. 2).

Helminth eggs were found during pollen analysis of latrine soil samples from Elden Pueblo. The 5 latrine deposits excavated at Elden Pueblo suggest increased parasitism with the passage of time. Eggs of 5 kinds of helminths were found at the site (Fig. 4). *Trichuris trichiura* eggs were the most abundant. Also present were eggs of *Ascaris lumbricoides*, *E. vermicularis*, taeniid cestodes, and hymenolepidid cestodes. Of the 7 samples dating from A.D. 1070 to 1150 only 1 contained helminth eggs. Of the 9 samples dating from 1150 to 1250, all contained helminth eggs. In 1 of these samples, 47% of the identifiable microscopic objects (including pollen grains and fungal spores) were helminth eggs. Although absolute quantification is not possible with the processed soils, it is apparent that parasitism was more common during the later part of the occupation and that parasitism may have contributed to the abandonment of the village.

DISCUSSION

It is of interest that none of the 100 feces examined from Dust Devil Cave contained helminth remains. The archaeological and dietary evidence indicates that the cave was used by a mobile group of hunter-gatherers. The small size of the cave (Reinhard et al., 1985) is suitable for a band of about 25 people but precludes habitation by a larger group. Only 1 other cave containing contemporary remains has been found in the area (Jennings, 1980), so it appears that the archaic population in Utah was dilute. It is probable that the aspects of small band size, mobility, and scattered habitations in a xeric environment reduced parasitism (Dunn, 1972). Also, it is possible that the diet of these people helped to limit parasitism. *Chenopodium* seed was found in 68 of the specimens. Although the poor preservation of the seeds makes species identification impossible, some of these seeds may have been derived from an anthelmintic species such as *Chenopodium graveolens*, which grows commonly on the Colorado Plateau. Callen and Cameron (1960) suggested that prehistoric Indian groups used *Chenopodium* as a vermifuge. Aztec use of *C. graveolens* as an anthelmintic has been verified by de Montellano (1975). A more com-

plete discussion of *Chenopodium* use in prehistory is presented by Reinhard et al. (1985).

Most of the agricultural sites show parasitism with *E. vermicularis* only. These sites include Salmon Ruin, the Chaco Canyon villages, and Turkey Pen Cave. The prevalence of infection is variable. The highest prevalence occurs at Turkey Pen Cave. This is surprising because this cave was occupied at a period when agriculture was new to the Anasazi and when Anasazi villages were small in comparison to the occupations of Chaco Canyon and Salmon Ruin, which date approximately 1,000 yr later. One might expect a higher incidence of *E. vermicularis* parasitism in the crowded village populations of Salmon Ruin and Chaco Canyon.

The coprolites from Antelope House are distinct from the other agricultural sites in that 4 helminth species are indicated. Two of these are dependent on moist soils for the completion of their life cycles (*Strongyloides* sp. and *Trichostrongylus* sp.). The presence of these parasites is probably related to the diet of the hosts. The utilization of cattail, willow, and horsetail as food items clearly indicates that the Antelope House population was linked to the riverine habitat in the bottom of Canyon de Chelly where the village was established. The presence of *Trichostrongylus* and *Strongyloides* indicates that foraging in moist areas exposed people to moisture-dependent parasites. The presence of *Strongyloides* larvae in coprolites from the village dogs indicates that the dogs were one reservoir of infection.

The discovery of hymenolepidid eggs in an Antelope House coprolite suggests another route of helminth infection. Stores of dried corn at Antelope House were probably infested with grain beetles and rodents, the typical intermediate and definitive hosts for hymenolepidids infective to humans. It is probable that the grain was not cleaned of grain beetles before grinding, and the consumption of beetles in ground corn resulted in hymenolepidid infection. Grain beetles have been reported through entomological analysis of Anasazi corn storage areas (Rohn, 1971).

The prevalence of *E. vermicularis* at Antelope House was relatively high (8 of 49 human feces). Considering the cramped living conditions and poor hygiene that are evidenced archaeologically, high pinworm prevalence would be expected.

The helminth parasites of Elden Pueblo may reflect the migratory habits of its population. The cool, dry environment of the Flagstaff area is not

conducive to the survival of *Trichuris trichiura*, the most common helminth found in the soil samples. Ecological reconstruction through palynology indicates a drier ecosystem at the time of occupation than that of today. Consequently, it is unlikely that *T. trichiura* could have maintained infection in the Elden Pueblo population. However, archaeological evidence shows a strong cultural connection between the peoples of the Flagstaff area and the peoples of the Verde River Valley 50 miles to the south. Paleontological evidence shows a strong connection between Elden Pueblo and riverine environments. It is likely that the population of Elden Pueblo was seasonally migratory and spent the cooler months in the warm, mesic Verde River Valley, where *T. trichiura* could have survived its extracorporeal embryonation period. The presence of *T. trichiura* supports the archaeological evidence of seasonal migration to a riverine habitat.

The analysis of coprolites for helminth remains is becoming increasingly important to New World paleopathologists as the evidence for pre-Columbian helminth parasitism increases. The high incidence of iron deficiency anemia in some areas, once attributed to corn dependency (El-Najjar and Robertson, 1976; El-Najjar et al., 1976), is being reconsidered. Until recently, it was believed that the New World in prehistory was free of helminth parasites such as hookworm, *Strongyloides*, and other worms that could have contributed to prehistoric anemia. Iron deficiency anemia is represented by the specific cranial bone lesions, porotic hyperostosis, and cribra orbitalia. An alternative hypothesis, implicating a combination of dietary insufficiency, parasitism, and disease (Steinbock, 1976), is gaining serious consideration by paleopathologists (Fink, 1985; Walker, 1985). It is of interest that the Anasazi skeletons excavated from Canyon de Chelly where Antelope House is located show one of the highest incidences of iron deficiency anemia. Helminth parasitism was possibly a contributing factor to iron deficiency anemia at this site and also at Elden Pueblo.

Coprolite research has already clarified details of prehistoric helminth biogeography. *Enterobius vermicularis* has been dated as early as 10,000 yr ago in North American peoples (Fry and Moore, 1969). *Trichuris trichiura* has been reported from Peruvian coprolites (Patrucco et al., 1983) and from Brazilian coprolites and a mummy (Ferreira et al., 1980, 1983). The same analyses of Brazilian materials demonstrated prehis-

toric hookworm infection, which supports a previous discovery from Peru (Allison et al., 1974; Dalton et al., 1976). An early report of *Diphyllobothrium* (Callen and Cameron, 1960) has since been verified by other studies of coprolites from North and South America (McClary, 1972; Patrucco et al., 1983; Ferreira et al., 1984). Other finds are summarized by Horne (1985).

Future coprolite research in the southwestern United States will address problems of prehistoric health as well as helminth biogeography. Perhaps of greater interest will be the application of coprolite study to understanding the ecology of prehistoric parasitism. This can be achieved through the combination of dietary and parasitological data derived from coprolites, ecological data derived from palynology, and archaeological information regarding prehistoric living conditions and habits.

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