The Paleoepidemiology of Schistosomiasis in Ancient Egypt

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Abstract

This paper reconstructs the paleoepidemiology of schistosomiasis in Egypt in the context of the parasite, host snail, and human ecology. The fossil snail fauna of the Sahara suggests that after its origin in East Africa, schistosomiasis existed in North Africa in prehistoric times. The oldest human cases were dated to Pharaonic Egypt. The development of irrigation in Egypt provided conditions favorable for schistosomiasis, especially Schistosoma haematobium *infection, and infection rates apparently increased until recent years. Recent countrywide epidemiological studies tend to confirm these findings. Implications of the paleoepidemiology of schistosomiasis for its control in modern Egypt are examined in relation to socioeconomic, demographic, and public health developments. Studies using new diagnostic tools that permit the screening of large numbers of mummies and naturally preserved bodies and correlation of their infection status with local environmental conditions may further elucidate the evolution of the schistosomiasis disease complex.*

Keywords: *Schistosomiasis, paleoepidemiology, Egypt, disease control*

Introduction

Schistosomiasis transmission takes place where the ecologies of the schistosome parasite, the aquatic snail intermediate host, and the human definitive host converge in space and time in surface waters. Climate and the distribution of surface waters suitable for snail intermediate hosts and the free-swimming parasite are crucial in the macrogeographic distribution of schistosomiasis worldwide. Microgeographic variations in the physical environment, human settlement patterns, the distribution of freshwater bodies and the intensity of exposure and contaminative contact by humans and the prevalence of the pathogenic worms and host snails largely determine the prevalence of infection within endemic areas and communities. Schistosomiasis transmission depends, unlike the transmission of malaria and other insect-transmitted diseases, on the active role of the human host in the transmission process, through excretory contamination of snail habitats and direct contact with infective water. This ecological relationship thus makes schistosomiasis a disease closely linked to rural water resources development, population increase, inadequate sanitation and lack of effective medical treatment (Kloos and Thompson 1979). In the 1990s, one or more of the five species of schistosomes causing disease in humans were endemic in all countries in Africa and in parts of the Southwest and East Asia and Central and South America and responsible for more than 200 million infections world-wide (WHO 1993). Egypt, which depends on the waters of the Nile for nearly all of its agricultural output, has some of the highest schistosomiasis rates in the world (Farley 1991).

The survival of the shells of snail intermediate hosts in favorable environments for thousands of years facilitates the study of schistosomiasis during historic and even prehistoric times. The two major schistosome species pathogenic to humans in Africa and the Middle East are *Schistosoma haematobium* and *S. mansoni*. The former, which causes urinary schistosomiasis and requires snails of the genus *Bulinus* for its life cycle, is known to have been endemic in ancient Egypt. *S. mansoni* causes intestinal schistosomiasis and is transmitted by *Biomphalaria* snails. Ruffer (l910) was the first to diagnose *S. haematobium* infections in mummies, a finding that caused widespread interest among medical scientists, historians, archeologists and linguists in the occurrence of schistosomiasis in ancient Egypt. The development of new diagnostic tools that are both nondestructive and reliable contributed to renewed interest in the study of the occurrence of schistosomiasis in ancient Egypt in recent years. The new diagnostic tools can provide more reliable diagnosis of schistosomiasis in preserved mummified materials than the written record, which is less specific, biased toward the nobility and difficult to translate from ancient Egyptian texts (Filer 1995). The earlier view that the Egyptian medical papyri contained descriptions of the symptoms of *S. haematobium* infections has recently been rejected (Nunn 1996, 2000; Westendorf 1992, 251), placing further emphasis on the study of infections in mummies, the distribution of snails transmitting schistosomiasis and life conditions of the ancient Egyptians.

Paleoepidemiology has become an important science in the reconstruction of disease histories in ancient societies. Most studies of schistosomiasis in ancient Egypt have used the paleopathological approach, which focused on diagnosis and history of disease, with little consideration of the ecologies of the schistosomes, the snail intermediate hosts and humans. Paleoepidemiology, a processual and population science which developed as a reaction to the narrow focus of paleopathology, considers the ecological and cultural relationships in disease complexes (Goodman 1998). In one of the earliest paleoepidemiological studies Dunn (l968) suggested that past and present hunter-gatherers were less inflicted with infectious disease than agriculturalists. By using ethnographic analogy (Inhorn and Brown 1997), Dunn was able to project current health levels of isolated hunter-gatherers into the past to describe infectious disease in prehistoric populations. The evolution of disease in hunting-gathering and agricultural societies was more intensively discussed by Cohen and Armelagos (l984). Extending the paleoepidemiological paradigm into the political sphere, Martin et al. (l984) argued that health levels in ancient Nubia were inversely associated with sociopolitical status and adversely influenced by political upheavals. Currently, paleoepidemiological studies are exploring avenues to better understand intergroup and local differences in health levels from a political-economic perspective (Goodman 1998).

No study has examined the distribution of fossilized snail species known to currently transmit schistosomiasis in Egypt and surrounding areas within the context of human ecology and schistosomiasis in ancient Egypt. Archeological studies have found *Bulinus* and *Biomphalaria* snails in numerous localities in much of Africa, including the Sahara and Sahel regions (Wendorf et al. 1976a; Beadle 1981; Brown 1994). The present distribution of intermediate host snail species and subspecies has facilitated the search for their evolution and the spread of schistosomiasis in Africa and questions the argument by some Egytptologists that it originated in Egypt (Wright 1976).

The objective of this paper is to reconstruct the paleoepidemiology of schistosomiasis in ancient Egypt and to evaluate the role of socioeconomic, demographic, and public health developments for its control. The prehistoric and historic record of schistosomiasis and its snail intermediate hosts, as well as archeological, ontological and historical evidence from Egypt and other Middle Eastern and African areas are examined to put the Egyptian material in a wider geographical context. Infection levels in contemporary Egyptian populations living in different localities and using different types of irrigation are projected into the past, to facilitate the reconstruction of the paleoepidemiology of schistosomiasis. The use of ethnographic analogy may be appropriate in the rural Egyptian population, whose lifeways and relationship with surface waters have not changed substantially in many ways through history. Particular attention is given to the probable origin and distribution of schistosomiasis in East and North Africa and the conditions which are known to favor its transmission and spread at the regional and, where possible, at the local level.

Evolution and Distribution of Schistosomiasis in Africa

The discovery of schistosome parasites in humans in 1851 by Dr. Theodor Bilharz in Cairo, the demonstration of their life cycle by Dr. Robert T. Leiper in Egypt in 1915 and Western political interests focused further attention on the early history of schistosomiasis in this country (Farley 1991). The great interest of European archeologists and historians in Egypt and the relative neglect of other civilizations in Africa also contributed to the view that schistosomiasis and several other infectious diseases originated in the lower Nile valley (Von Oefele 1901; Wright 1976). This anthropocentric approach to schistosomiasis put too much emphasis on the human phase of the schistosome life cycle and neglected the ecology of the parasite and snail hosts. Studies of the paleoecology of the parasite, the intermediate hosts and humans argue that schistosomes existed together with their human host around the headwaters of the Nile much earlier, at least as early as the Paleolithic (Wright 1970). According to Davis (l992), both schistosome species and their snail hosts originated in Gondwanaland. But recent phylogenetic studies indicate that *Biomphalaria* came to Africa from South America or North America after the breakup of the super continent, about 2 to 5 million years ago, and that the human schistosomes originated in Asia (DeJong et al. 2001; Morgan et al. 2001; Snyder and Loker 2000). An early date is also supported by the adaptation of schistosome parasites to primates (Platt and Brooks 1997). In East Africa, where the australopithecines and their successors lived in close proximity to freshwater bodies, baboons continue to be an important reservoir host of *Schistosoma mansoni* (Fenwick 1969; Wright 1970). Subfossilized *Bulinus* and *Biomphalaria* snails have also been found in the more arid parts of East Africa (Beadle 1981, Brown 1973; Gautier 1976). The presence today of a rich snail fauna in East Africa (about half a dozen species each of *Biomphalaria* and *Bulinus*, including four subspecies of *Bulinus truncatus* in Ethiopia (Brown 1994)), further suggests that schistosomiasis evolved in that region. The relative scarcity of snail fossils in the East African Lakes region is apparently due to its humid and acidic soils, which disfavor the survival of snail shells, unlike the soils of arid areas (Sparks 1970).

The wide distribution of subfossil *Biomphalaria alexandrina* (currently the major transmitter of *S. mansoni* in Egypt), *B. pfeifferi* and *Bulinus truncatus* at numerous Paleolithic sites in the Sahara (including the desert of Egypt) as far south as the Sahel belt in Sudan and Chad, indicates that schistosomiasis was endemic in North Africa during prehistoric pluvial cycles which ended during the early Neolithic period. Several wet phases have been identified in the Sahara between 22,000 BC and 3,000 BC, based on lake levels. In pre-Dynastic times, high lake levels existed throughout Africa between 7,000 BC and 6,000 BC and again from 4,500 BC to 3,000 BC. Populations inhabiting the present region of the Sahara fished and collected shellfish for food in extensive freshwater lakes and marshes in a region characterized by a rich flora and fauna. The fauna included wild and domesticated cattle, fish and shellfish, crocodiles, rhinos, buffalos, hippos and many other species of tropical Africa (Beadle 1981; Street and Gasse 1981; VanDamme 1984; Wendorf et al. 1976a).

This archeological record questions Adamson’s (l976) suggestion that schistosomiasis entered Egypt during Pharaonic times along trade routes from the south and subsequently spread throughout the Middle East. It is more likely that schistosomiasis was endemic in various parts of North Africa much earlier. Movements of settlers from the slowly desiccating Sahara to the fertile Nile valley and the southern margin of the Sahara and adoption of an increasingly nomadic economy based on animal husbandry in the affected areas (Barker 1981; Close 1987) provided opportunities for the spread of schistosomiasis and its host snails throughout North Africa, and especially into Egypt. Live snails could have been disseminated by hunters, farmers and pastoral nomads transporting them in water containers and on birds, as reported in recent years (Kloos and Thompson 1979).

The Fossil Snail Record

Although schistosomiasis-transmitting snails were widespread in Africa and the Middle East during prehistoric times, the advent of irrigated agriculture and concomitant rapid population growth greatly favored the spread of schistosomiasis. The finding of fossilized *Bulinus truncatus* (but not *Biomphalaria*) shells at late Paleolithic sites at Edfu and Esna in Upper Egypt (Wendorf et al. 1976b) indicates that conditions suitable for *S. haematobium* transmission existed in the Nile valley at that time. Failure to recover snail shells elsewhere in the Nile valley and delta at later Pharaonic sites appears to be related to the long massive aggradation of alluvial soil which tends to cover and obliterate fossil remains. Similarly, in the Gezira irrigated area of Sudan, no *Biomphalaria* and *Bulinus* subfossils were found in alluvial soil but they were common in unaggregated soil. Large-scale irrigation schemes, typically located on alluvial soil, have been afflicted with some of the highest schistosomiasis infection rates (Malek 1958; Hunter et al. 1994). The recovery of numerous fossilized *Bulinus* shells from mudbrick houses along irrigation canals and around several palaces in Mesopotamia dating from 4,000 BC to 300 AD further indicates that irrigation systems were suitable schistosomiasis transmission sites in ancient times (Zakaria 1959). Recovery of *Bulinus truncatus* from a well in the town of Jericho dated at 1,650 BC (Biggs 1960) also suggests that snail hosts became adapted early to human-made aquatic habitats in and around early settlements. As with other density-dependent parasites, especially *Ascaris* and hookworm, the change from hunting/gathering to a sedentary agricultural lifestyle created conditions that facilitated schistosome transmission (Cockburn 1971). Thus the creation of human-made snail habitats through the construction of canals and ponds, intense human use of Nile water and the rapidly increasing human population near these waters without adequate sanitation facilities all favored the close interaction between humans, the parasite and the snail intermediate host.

Mummy Studies

The earliest case of human schistosomiasis (*S. haematobium*) identified using immunodiagnosis (ELISA) occurred over 5,000 years ago in an Egyptian adolescent (Deelder et al. 1990). ELISA also revealed *S. haematobium* in two mummies 3,000 and 4,000 years old (Contis and David 1996). The two *S. haematobium*-positive mummies diagnosed by Ruffer (l910) were dated to the Twentieth Dynasty (1250-1000 BC). Ova of this parasite and of tapeworm were found radiologically in the naturally preserved (by desiccation) body of a 14 year old boy of similar archeological age who was a weaver by trade and had liver cirrhosis, a common symptom of chronic schistosomiasis (Lewin 1978). Calcified schistosome ova were identified radiologically in several mummies from later periods by the Manchester Mummy Project (Contis and David 1996). Radiological examinations also strongly suggest that the calcified bladders in two other mummies were due to *S. haematobium* infection (David 1997). As yet, the research shows no evidence that *S. mansoni* existed in ancient Egypt. The recent use of non-invasive diagnostic tools will permit epidemiological studies of larger and representative mummy populations. The Manchester Mummy Project, using computed tomography (CT) scanning, scanned electron microscopy (SEM), the enzyme linked immunosorbent assay (ELISA) and immunocytochemistry, has developed a program to study the paleoepidemiology of schistosomiasis in ancient Egypt (David 1979, 1997; Contis and David 1996). Cockburn (1998) estimated that several million mummies remain in Egypt. Partly because the highly effective Egyptian method of mummification was not used in other African and Middle Eastern civilizations, apparently no human remains with soft tissues have been studied in Mesopotamia, Israel, or other schistosomiasis-endemic areas.

The only archeological evidence of schistosomiasis haematobium endemicity in ancient Assyria and Mesopotamia, besides subfossil snails, were phallic-shaped boundary markers (*kudurru*) made of stone. Inscriptions on these stones warned persons intending to move them of urinary diseases and painful urination (Richter 1913). Used first exclusively for the royalty, mummification increasingly became the choice of burial method for the upper and middle classes during the time it was practiced in Egypt (2600 BC to 600 AD). The poor continued to be buried in shallow graves in the desert, another effective method of preserving the body in Egypt's arid environment. The process of mummification is essentially the evisceration and drying out of the body, usually by using natron (sodium carbonate). The kidneys and the heart were usually left in place but the intestines, stomach, liver and lungs were removed and placed in canopic jars. Mummification practices were discontinued after the Arab invasion in the seventh century AD (David 1997). Coprolite studies, which have already contributed substantially to the paleoepidemiology of intestinal helminthiases in prehistoric populations in several countries (Inhorn and Brown 1997), could be used to expand the Egyptian evidence. The survival of numerous human remains in other parts of North Africa, Asia, Europe and the Americas, and the development of new diagnostic techniques that permit diagnoses from minute amounts of tissue, are increasingly facilitating paleoepidemiological studies outside Egypt (Cockburn et al. 1998).

The Historic Record

The proposed existence of historical evidence of schistosomiasis in ancient Egypt in the form of medical writings and art forms (paintings, relief and sculptures) presumes that Egyptians either were able to identify the parasite or the specific symptoms of schistosomiasis, particularly the urinary form. Some Egyptologists interpreted the hieroglyph for *âââ* disease, shown in the Ebers Papyrus as the determinative discharging phallus, to mean haematuria was caused by schistosomiasis (Ebbell 1937; Ghalioungui 1962). But there is no unequivocal word in ancient Egyptian for haematuria and since 1961, after extensive philological debates, Egyptologists have generally accepted that the determinative meant semen or poison, reflecting the Egyptian concept that disease can be transmitted by an incubus, impregnating a victim with poisonous semen (Nunn 1996, 2000; Westendorf 1992). The larger *Ascaris* and pinworms, by contrast, were recognized and correctly described in the papyri and in medical treatises of other early civilizations (Nunn 2000; Sandison 1967).

Schistosomiasis Exposure Risk in Ancient Egypt

Due to the focus of past Egyptology research on mortuary and religious complexes, relatively little is known about the daily life of Egyptian peasants during the three millennia of Pharaonic rule other than what the royal scribes and artists wrote and painted and what we know from Greek writers. However, existing evidence suggests that many aspects of their lives differed little from today, even though the Aswan Dam and the introduction of modern education, electricity, radio, television, motor pumps and chemical fertilizers have changed some aspects of rural life. Conditions in the village communities would have predisposed the population to infection, and working and recreational activities would have brought many people into direct contact with infective water near riverbanks and in the canals.

Beginning in pre-Dynastic times (before 3200 BC) the Egyptians developed an extensive irrigation system, characterized by the Nile's annual flooding of basins but was increasingly based on the control and regulation of the Nile. Once the waters had receded from the land in the fall, the peasants began the cycle of cultivating Egypt's food crops. Two kinds of wheat (spelt and emmer) and barley were grown, providing the basic ingredients for the staple diet of bread and beer. Seed was scattered on the earth and then plowed into the soil; the harvest was gathered in the spring (Caminos 1997). Another agricultural crop was flax, used to spin linen, which was widely used for clothing and domestic purposes as well as for mummy bandages (David 1999). Irrigation was carried out only once a year in antiquity, allowing the fields to be watered and cultivated, but Egyptian peasants also grew a variety of vegetables, fruits and other crops near the irrigated basins using perennial irrigation. These basins were regularly fed with water by the river, and the gardeners also transported water to these areas, either bringing it from the Nile in large pots or by using water-lifting devices known today as *shaduf* (pole and bucket lever) (Hemden 1961).

Daily life in ancient Egypt also resulted in frequent and intense contact with Nile and canal water in the domestic sphere. Fetching water, washing clothes and utensils, and bathing were carried out at the riverbank and in canals, and sailing and swimming were constant activities. Fishing was an important source of protein for the population due to the general scarcity of meat. Brickmaking was another activity, which involved close contact with water. Some tomb paintings of peasants, boatmen, papyrus carriers and other rural people in the Sakkara necropolis show distended abdomens and other deformities that may be due to schistosomiasis (Ghalioungui 1962). Numerous written records and illustrations depict a rural life style characterized by a strong dependence on the Nile for all occupational, domestic and recreational needs and poor sanitary conditions in the villages that have hardly changed over time (Caminos 1997).

However, it is not surprising that evidence of schistosomiasis is present in the mummified bodies of both the wealthy classes and the peasants. Upper class Egyptians commonly sailed on the Nile, hunted waterfowl, and had close contact with the ornamental lakes and ponds featured in the gardens of their villas.

Population Growth and Irrigation Development in Egypt

Land use and demographic development in Pharaonic Egypt were increasingly determined by irrigation agriculture. Butzer (1976) estimated that Egypt's population was 0.35 million around 4,000 BC during the pre-Dynastic period, when about 16,000 square kilometers of land were available for cultivation using rudimentary flood irrigation methods. This period was characterized by low population pressure on the land, with a substantial component of pastoralism, hunting, gathering and fishing. By 150 BC, the population had increased to an estimated 4.9 million and the cultivable area to 27,000 square kilometers, with the animal-drawn waterwheel (*saqia*) and the *shaduf* in use, permitting basin irrigation of levees and valley margins outside the sphere of gravity flow. This population was considerably larger than Egypt's population of 3 million in the early nineteenth century (Watts and El Katsha 1997). The annual fluctuations and long-term decline in Nile floods after the end of the last major wet phase around 3,000 BC, together with population increase, large labor-demanding state projects and later colonial agricultural exploitation by Rome, increased the need for more food through intensive basin irrigation and multiple cropping. In addition to the summer flood crops, during the Ptolemaic period it was possible to raise a second crop during the winter (Butzer 1976).

The large extent of the irrigated area in Dynastic Egypt is illustrated by the fact that this acreage was not surpassed until around 1880 (Butzer 1976). The Fayum and the Memphis area at the head of the delta, together with the Luxor and Aswan areas in Upper Egypt, had by far the largest population densities and the most intensive irrigation technologies due to their proximity to regional capitals. The characteristic urban-rural sociopolitical relations and government ownership of all irrigated land put pressure on peasants to produce food and fiber to supply the royal, nobility, clergy and lower administrative segments. Butzer (1976) identified 217 Dynastic cities, large and small centers, and villages (excluding many smaller villages not mentioned in the official records). He estimated that population densities ranged from under 75 persons per square kilometer to over 500/sq km, with a mean density of 172/sq km. The location of villages on Nile levees within the irrigated areas for the purpose of protection from floods and proximity to the fields and canals assured close contact of the rural population with the canal system.

Large-scale perennial irrigation in Egypt began with the reign of Mohamed Ali (1805-1848), who promoted the cultivation of long staple cotton, a major Egyptian export crop (Watts and El Katsha 1997). With the construction of the Low Dam at Aswan and the barrages north of Cairo after 1900, the period of winter irrigation closure could be further reduced to 6-7 weeks, and after the construction of Aswan High Dam in 1964, to 2-3 weeks. The shorter closure period permitted aquatic snails to flourish in the absence of the annual drying out of canals. The impact of perennial irrigation was recorded in four villages in the Kom Ombo area in Upper Egypt, all under basin irrigation. In 1934, 11 percent of their inhabitants were infected with *S. haematobium* and by 1937, after the introduction of perennial irrigation using water pumps, infection rates had increased to 44-75 percent (Khalil and Azim 1938). Thus within three years infection rates had become as high as those in the delta, where perennial irrigation had been in use since the mid-nineteenth century. Conversely, relocation of Nubians displaced by the Aswan High Dam in the Kom Ombo area was associated with a decline in *S. haematobium* infection rates from 23 percent in 1964 to 5 percent in 1976. This decline has been attributed to their relocation on rocky outcrops and along the Nile at a greater distance from their irrigated land, employment of hired laborers from outside communities and provision of wells for domestic use (Miller et al. 1978, 1982). The beneficial effect of wells and Nile rather than canal water on schistosomiasis has been reported by different investigators (Kloos et al. 1983; Miller et al. 1978).

These divergent outcomes illustrate the complexity of environmental, socioeconomic, and human behavioral factors in microgeographical and temporal changes in schistosomiasis distribution during relatively short time periods. These findings also serve as a caution against generalizations about the impact of irrigation and rural living conditions on schistosomiasis distribution and suggest that similar variations may be found in ancient Egypt. Comparative biological studies already underway on DNA sequencing of modern and ancient Egyptian populations that focus on kinship research, sex identification, population movements and diagnosis of disease are providing new information on the geographic and cultural demography (Filer 1995) necessary for paleoepidemiological studies.

Schistosomiasis in Egypt Since the Pharaonic Period

Little is known about the occurrence of schistosomiasis in Egypt and the Middle East during the two millennia between the end of the Pharaonic period and the mid-nineteenth century, when the schistosomes and their life cycle were discovered by modern science. The only evidence of the occurrence of schistosomiasis in medieval Egypt is its immunodiagnosis in 15 out of 23 mummies from 35-550 AD in the Wadi Halfa riverine area near the Egypt-Sudan border (Miller et al. 1992). This study is of particular epidemiological interest because it provides information on the sex and age distribution of infection: 7 males and 7 females, with one mummy's sex not identified, and all heavy infections were in individuals above 15 and below 40 years of age. This age/sex distribution of schistosomiasis still prevails in Egypt today. During the period of Roman occupation the use of the ox-driven water wheel in Upper Egypt permitted intensive irrigation. In the sixteenth century, the Prospero Alpini observed and reported on haematuria in Egyptian males and the widespread problem of bladder stones in the population of Lower Egypt. French army physicians focused on these symptoms during Napoleon's invasion of Egypt, but without knowing the etiology of schistosomiasis, attributed them to the local climate and faulty perspiration (Hoeppli 1969; Renoult 1803), and soldiers were instructed to wear condoms as a preventive measure (Girges 1934, 1). Other French writers reported on the occurrence of haematuria in caravans crossing the Sahara from Timbuktu (Girges 1934).

Lack of information on the distribution and transmission of schistosomiasis in ancient Egypt does not permit inferences about its evolution and persistence during Egypt's history. However, there is evidence that *S. haematobium* is still being transmitted in some localities in Saudi Arabia and Iraq where it was endemic in the past. The Prophet Mohamed cautioned worshipers against drinking water from a certain spring north of Mecca to prevent red blood in urine. Reference to haematuria in the medical texts of several well-known Arabian physicians, including Ibn Sina (Avicenna), Ibn Hubal and Al-Majousi (Alio 1967), indicates that urinary schistosomiasis was still endemic in the Arabian peninsula between the tenth and thirteenth centuries. *Bulinus truncatus* is still found today in springs in the surroundings of Medina (Brown and Wright 1980). In Iraq, the fossilized *Bulinus* snails were found in the same areas where schistosomiasis was endemic in recent decades (Baquir and DeMorais 1963).

In the mid 1990s, 12 percent of the Egyptian population was infected with *S. mansoni* and 6 percent with *S. haematobium*, but in smaller agricultural villages where life continues much like in ancient Egypt, prevalence rates over 50 percent are still found (El-Khoby et al. 1998). The most intensive epidemiological research project ever carried out by the Egyptian government (17,172 households in 251 rural communities and in 9 of the country's 14 governorates) showed considerable variation in the prevalence of the two types of schistosomiasis among the different governorates. Much of the variation in prevalence among villages and governorates was due to the type of irrigation used, with the highest rates in localities where perennial irrigation prevailed and the lowest rates in basin irrigated areas. Rates were also higher in smaller villages, where nearly all residents are *fellahin* (subsistence farmers), poverty is most severe, and contact with the canals most intense (El-Khoby et al. 2000b). These conditions prevailed in ancient Egypt, except that few canals were used for basin irrigation.

S. mansoni overtook *S. haematobium* as the predominant schistosome species in Egypt between the 1930s and 1990s because of increasing river regulation, intensified farming and population increase in the Nile valley and delta. *Biomphalaria alexandrina* snails spread into Upper Egypt, where they were first reported in the 1970s. *Bulinus truncatus* populations declined and *S. haematobium* rates ranged from 5 to 9 percent in the 3 governorates studied in Upper Egypt, peaked at 14 percent in Fayum and were generally lower than 1 percent in the 5 Lower Egyptian governorates studied. *S. mansoni* ranged from 0.4 to 1 percent in Upper Egypt, 4 percent in Fayum and from 17 to 43 percent in Lower Egypt. The intensity of infection, which tends to be closely associated with severity of disease, varied similarly among these governorates (Cline et al. 1989; El-Khoby et al. 2000a; Scott 1937).

Construction of the low dams (barrages) around the turn of the nineteenth century and especially Aswan High Dam in 1964 and concomitant increases in canal systems and perennial irrigation, changes in the flow regime, silt load and pollution levels of Nile water, and increases in aquatic vegetation were all instrumental in these changes. Specifically, *Biomphalaria* snails are more tolerant of low oxygen and pollution (organic and chemical) levels and prefer more slowly flowing water than *Bulinus* (El-Khoby et al. 1998; Watts and El Katsha 1995). Preference of host snails of *S. mansoni* for perennially irrigated areas and of transmitters of *S. haematobium* for natural water bodies has been noted elsewhere in Africa (Kloos et al. 1988). Greater suitability of the ancient, more pristine and less controlled riverine environment for *Bulinus truncatus* and failure to recover fossilized specimens of *Biomphalaria* in Egypt's Nile Valley, as well as other parts of the arid Middle East, indicate that *S. mansoni* infections were rare in ancient Egypt.

Although living conditions and water use behavior in rural ancient Egypt are now fairly well known, reliable reconstruction of the distribution of schistosomiasis by age, sex and socioeconomic status in different parts of the country will have to await the study of larger and representative populations of mummies and naturally preserved bodies using modern diagnostic techniques. The extensive epidemiological studies of the Ministry of Health in the 1990s showed that males generally had higher infection rates than females, due to gender division of agricultural work, swimming and bathing in canals. Older children and adolescents were the most heavily infected age group. Similarly, the male/female infection ratio was much higher among farming populations and in Upper Egypt due to differences in gendered water contact behavior and transmission patterns. Moreover, both *S. haematobium* and *S. mansoni* infection rates varied considerably among communities (El-Khoby et al. 2000b; Watts and El Katsha 1997).

Implications for Schistosomiasis Control

Although the extension of perennial irrigation and the increase of the Egyptian population provided conditions favorable for schistosomiasis transmission, the national schistosomiasis control program that was gradually expanded after 1918 (together with increased urbanization, diversification of the economy and the changes in the rural villages) resulted in the accelerating decline of schistosomiasis. The population increased from 28 million in 1960 to an estimated 69 million in 2000, of which 46 million lived in urban areas. In 1993, 99 percent of the Egyptian population had access to health services and 90 percent to safe water, the highest rates of any African country (United Nations Development Programme 1995, 158). *S. haematobium* rates declined from around 60-70 percent in most districts in 1925 (Girges 1934, 107) to 56 percent in 1935 and 5 percent in 1996, and *S. mansoni* rates declined from 32 percent in 1935 to 12 percent in 1996 (Cline et al. 1989; El- Khoby et al. 1998).

In spite of the recent decline of schistosomiasis rates in Egypt, both *S. mansoni* and *S. haematobium* became endemic in all desert areas reclaimed for irrigation agriculture since 1952 and surveyed for schistosomiasis, including farms on the Sinai Peninsula and in the eastern delta (Mehanna et al. 1994). This situation again suggests that schistosomiasis (especially *S. haematobium*) spread rapidly among the irrigated areas of ancient Egypt.

The strongest link between epidemiological patterns of ancient and modern Egypt were found in small rural villages (*ezbas*), which are characterized by the highest *S. haematobium* and *S. mansoni* infection rates, large proportions of *fellahin*, and the fewest safe (piped) water supplies, sewage disposal sites, clinics and other public services. In this traditional environment, exposure intensity with canals, which is strongly correlated with intensity of infection, resulted in schistosomiasis prevalence rates several times higher than in larger villages and towns (El-Khoby et al. 2000a).

It is of interest that no clear descriptions of haematuria survive from ancient Egypt although they may be couched in different terminology in the medical papyri. Evidence from the Assyrian boundary markers and the oral history from the time of the Prophet Mohamed suggest that ancient Egyptian physicians and the general population were also familiar with haematuria in schistosomiasis. By the early twentieth century, the Egyptian population was well aware of the widespread occurrence of haematuria to the point where the passing of blood by boys was considered as a normal and even necessary part of growing up, a form of male menstruation linked with male fertility (Girges 1934, 103). They also knew that contact with canal water was more likely to result in "bilharzia" (schistosomiasis) than Nile water, which has traditionally been highly revered for its "sweet water" with life-giving properties. But Egyptians apparently learned only recently about the disease itself and the role of snails in transmission from clinic and school teaching (Girges 1934, 521; Kloos et al. 1983). Other illnesses have reportedly been linked to schistosomiasis, such as exposure to the sun, eating unripe sugar cane and walking barefoot (Kloos et al. 1982; Mehanna et al. 1993), further indicating that the ancient Egyptians did not know the specific cause of schistosomiasis — the hardly visible schistosomes.

The discrepancy between the high level of knowledge about the association between contact with canal water and schistosomiasis on the one hand and continuation of risky contact behavior on the other is due to the population's continued dependence on the canals and Nile for all aspects of life — food production, domestic chores, recreation and religious ablution. This situation and the perception that this common disease is relatively mild contributed to the continuation of the transmission cycle of the schistosomes. Contaminative activities such as washing soiled clothes of children, excretion directly into the water by children, ablution, and discharge of raw sewage still result in high snail infection rates. Further, exposure type activities such as bathing, swimming and washing utensils have also been associated with high transmission rates to humans (Kloos et al. 1983; El-Khoby et al. 2000a). The discrepancy between the perception of high schistosomiasis risk and persisting exposure has been a barrier to recent nationwide health education campaigns using TV spots (Mehanna et al. 1994) that emphasized the need to eliminate contacts with the canals and the Nile without providing alternatives (Loza and El-Tawil 1992). The few pilot projects providing swimming pools for children failed due to their poor maintenance and opposition by local civic and religious leaders (Mostafa 1993; Kloos et al. 1983). Provision of piped water from wells often failed to reduce contact with the Nile and canals significantly due to its brackish nature (Kloos et al. 1983; El Katsha et al. 1989). In 1952, the Egyptian government made it a policy to upgrade the standard of living of the rural population, especially through the provision of potable and safe water, resulting in exceptionally high water supply coverage among developing countries. Nevertheless, smaller villages and the more isolated Upper Egypt region continued to be relatively neglected (Watts and El Katsha 1995). Rockefeller-supported research projects in the 1930s and in 1948-1952 concluded that the introduction of household latrines in several villages in the Nile delta had no significant impact on schistosomiasis because most contamination of water supplies occurred in the fields, and the pit latrines were unsanitary and seldom used (Scott and Barlow 1938; Weir et al. 1952). Other preventive measures, including the elimination of surface canal and drainage water by underground drains and sprinklers, have not been considered on a large scale. Earlier attempts to kill the host snails by periodic drying of perennially irrigated fields and closure of drains, as well as application of molluscicides, failed due to the ability of host snails to hibernate in mud and its reinvasion of treated areas from untreated areas upstream (Leiper 1915; Farley 1991). Area-wide use of molluscicides has been increasingly opposed by the Egyptian government and the World Health Organization due to their inefficiency in extensive canal networks, their high cost, potential health risks and ecological impact (fish kill) (Kessler et al. 1987). Although the ecologies of the snail intermediate host, the parasite and human behavior are influenced by the activities of various government agencies, there is no intersectoral collaboration between ministries that could foster the expansion of preventive strategies. This lack of a broadly based control strategy that extends beyond the present emphasis on chemotherapy is thus impeding progress toward schistosomiasis control (Watts and El Katsha 1995).

In spite of the current predominance of *S. mansoni* in most Egyptian communities, the provision and utilization of diagnostic services in rural areas failed to consider this change in schistosome ecology. A combination of the long predominance of *S. haematobium* in Egypt, the easily recognized signs and symptom of haematuria and bureaucratic bottlenecks were instrumental in this misconception. As a result, the great majority of villagers in different parts of the delta associated schistosomiasis with haematuria and *S. haematobium* infection, even though *S. mansoni* was by far the most common parasite. Several investigators have recommended that both villagers and local health workers receive health education to remedy this situation (El Katsha and Watts 1995; Mehanna et al. 1994).

The ever-increasing consumption of Nile water for agricultural, industrial and domestic needs in Egypt is at risk of being curtailed by international agreements between the Nile countries concerning ecological problems. In addition to the 55.5 billion cubic meters granted to Egypt under the 1959 Nile Waters Agreement, 2.6 billion are available from subsurface sources and 4.6 billion from recycled drainage water. But Egypt is using another 5 billion cubic meters a year due to limited utilization by the Sudan of its share. This additional supply will most likely be curtailed as Sudan and Ethiopia continue to expand their own irrigated areas and industries (Radwan 1997). The increasing demand/availability ratio is predicted to lead to a serious water shortage in Egypt by 2010 (Watts and El Katsha 1995). Additional problems of water wastage, drainage, water logging, a rising water table and associated sanitation problems demand increased conservation and irrigation efficiency measures. They also point out the need for water conservation, especially since irrigation agriculture consumes by far the largest amount of water in Egypt (Radwan 1997; Egyptian Environmental Affairs Agency 1992). Elimination of canals and open drains through sprinkler and drip irrigation and concomitant expansion of piped systems providing safe and acceptable domestic water would significantly contribute to the control of schistosomiasis and other water-related diseases. The current bureaucratic approach, characterized by central planning and the failure to consider the ecological impacts of irrigation and water conservation, has resulted in excessive irrigation due to erroneous assumptions and calculation of water needs and supplies. Failure to meet the specific irrigation needs for different crops and soil types in many areas has also alienated many farmers. The oversupply is reflected in the accumulation of excess water at the distant end of canals and drains (Radwan 1997), which are important in schistosomiasis transmission (Watts and El Katsha 1995; Farooq et al. 1966). Heavy-handed government involvement in irrigation agriculture similarly increased risk of schistosomiasis infection in ancient Egypt, as described above. Increased farmer water control through the water user associations has been associated with greater irrigation efficiency, which not only boosts crop production in the increasingly diversified agriculture of Egypt (Hvidt 1996) but also reduces the problem of water logging and salinization.

The general decline in schistosomiasis rates in Egypt in recent decades is in contrast to the situation in most other African countries where rates have increased, apparently due to the intensive schistosomiasis control and water supply programs (Bergquist 1998). Two non-African countries stand out for their achievements in control. First, in Japan, another irrigation society, the combined effects of socioeconomic development and an intensive molluscicidal and chemotherapy program led to the disappearance of schistosomiasis. Mechanization of agriculture, especially the change from water buffaloes (the major definitive host of the parasite besides humans) to tractors, urbanization/ industrialization and environmental modification (especially cementing of canals and leveling of snail habitats) were major factors in Japan's control of schistosomiasis (Sasa 1970). Second, Puerto Rico achieved control merely through socioeconomic development after the termination of its schistosomiasis control program in 1980 (Hillyer and Soler de Galanes 1999).

Conclusion

The archaeological and written record of ancient Egypt and surrounding countries and the projection of recent trends and patterns in schistosomiasis into the past permit a preliminary reconstruction of the paleoepidemiology of this disease complex. Available information on the evolution of the parasite, the snail intermediate hosts and humans indicates that schistosomiasis originated in East Africa and became widely distributed in North Africa during prehistoric wet phases. The physical and human environment of the Nile valley and delta provided increasingly favorable conditions for the transmission and spread of schistosomiasis caused by *S. haematobium* after the development of irrigation agriculture during the early Pharaonic period. Although the snail fossil record is poor in the ancient Nile valley and delta, *Bulinus truncatus* host snails were probably widespread, also indicated by their recovery from irrigated areas and wells elsewhere in the Middle East. The occurrence of *S. mansoni* during historic times cannot be determined from available information but seems to have been rare, based on environmental data and the ecology of its intermediate host. The ascendancy of this parasite as the major schistosome species in Egypt during the last few decades appears to be related to the ecological changes caused by the construction of Aswan High Dam, subsequent perennial irrigation and the relatively greater adaptability of its host snail, *Biomphalaria alexandrina*. The accidental introduction of the South American snail *Biomphalaria glabrata* into Egypt around 1990 is resulting in further changes in the prevalence and transmission dynamics of *S. mansoni* (Yousif 1998).

Institutional control of irrigation and agricultural production are linked to the past. The extensive dam and canal building programs of the government had their incipient beginnings in Pharaonic Egypt. They are the major underlying causes of the recent increase in *S. mansoni* and decrease in *S. haematobium*. Although the national control program and socioeconomic development have made major inroads into schistosomiasis, they have not been able to prevent its spread into newly reclaimed areas. This situation further reflects the inappropriateness of outdated, water-wasting, state-planned perennial irrigation methods. The availability of new, efficient irrigation techniques and the urgent need to conserve Egypt's limited water resources argue for major structural changes in irrigation agriculture involving increased farmer control of water. But this will also require increased health education of the rural population informing them of the changing epidemiology of the two types of schistosomiasis and the health risks of *S. mansoni* infection. Whether this is possible will depend largely on the ability of the Egyptian government to restructure the ministries of agriculture and irrigation to eliminate irrigation inefficiency and promote farmer involvement in all aspects of irrigation and community development. Moreover, the activities of various ministries dealing with irrigation and rural development need to be integrated to more effectively deal with all aspects of schistosomiasis transmission and control. The intersectoral approach with a focus on prevention has repeatedly been advocated by the World Health Organization in view of the complexity of schistosomiasis ecology and the difficulty of disrupting the transmission cycle (WHO 1993).

Using the paleoepidemiological approach and the method of anthropological analogy, we addressed questions of the origin, spread and environmental prerequisites and conditions for the transmission of schistosomiasis in ancient Egypt. Further study of larger, representative mummy populations and of naturally preserved human remains in archeological sites using new diagnostic techniques can elucidate epidemiological patterns of schistosomiasis at the community and district levels.

Endnote

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