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Case study

Mid-7th century BC human parasite remains from Jerusalem

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ABSTRACT

Objective: To determine the species of intestinal parasites present in 7th century BC high-status residents of Jerusalem and to expose the history of regional health and sanitary conditions.
Materials: Fifteen sediment samples were collected from the cesspit below a stone toilet seat found at the site of Armon Hanatziv, southern Jerusalem. The toilet installation was located in a garden adjacent to a monumental structure with extraordinary architectural elements.
Methods: A light microscope was used to identify and measure the eggs.
Results: The presence of four intestinal parasite egg taxa was detected: *Trichuris trichiura* (whipworm), *Taenia* sp. (beef/pork tapeworm), *Ascaris lumbricoides* (roundworm), and *Enterobius vermicularis* (pinworm). This is the earliest appearance of roundworm and pinworm in the ancient Israel parasitological record.
Conclusions: Findings reveal that intestinal parasitic diseases most likely caused by poor sanitary conditions were a human problem in the Late Iron Age of Israel, affecting even high-status groups.
Significance: The study demonstrates the potential of archaeoparasitological investigations to expand our knowledge of the origin and history of regional infections. Moreover, parasitological evidence enabled us to determine the purpose of the cubical perforated stone artifacts (stone toilet seats rather than cultic objects as currently debated).
Limitations: The eggs of some parasite taxa are less durable, so may theoretically be absent due to selective preservation.
Suggestions for Further Research: Future excavations of ancient Israel should include archaeoparasitological studies of rare toilet installations to prevent information loss of regional history of diseases and to better understand their archaeological context.

1. Introduction

Studies of intestinal parasite remains preserved in ancient feces deposits (archaeoparasitology) are an important tool for tracing the evolution of past infections worldwide. Archaeoparasitological studies can also provide significant information on standards of health and sanitation prevalent in ancient societies (Reinhard and Bryant, 1992; Bouchet et al., 2003; Le Bailly et al., 2006). These studies are aided by the fact that intestinal parasitic worms that infect humans lay thousands of exceptionally durable eggs per day. Once the eggs are passed into the open environment, they become a permanent archaeological record of diseases (Reinhard and Warnock, 1996; Mitchell, 2017). Parasitological studies of pinworms found in humans, great apes, and lesser apes demonstrate that pinworm evolution paralleled primate evolution. Hence, pinworms have been a nuisance since the beginning of humankind (Hugot et al., 1999).

Other parasites have more recent origins. Studies of the last several decades comparing the parasitic environment of hunter-gatherers and farming communities have demonstrated that the dramatic changes in diet, settlement patterns, and social organization caused by the advent of agriculture and, specifically, the domestication of animals, triggered the intensification in the parasitosis of humans (e.g., Reinhard, 1988). In contrast, the impermanence of hunter-gatherer settlements significantly reduced their exposure to transmissible diseases, airborne and food-borne parasites, and fecal pollution. Modern nomadic communities of hunter-gatherers that settle and eventually become farmers reflect this pattern. Rates of intestinal worms that cause anemia and delayed growth, with potentially dramatic consequences for the psychic development of children, have generally risen with a sedentary way of life (e.g., Dounias and Froment, 2006). As the birthplace of sedentism and domestication of plants and animals (Bar-Yosef and Belfer-Cohen, 1989; Zohary et al., 2012; Langgut et al., 2021), the Fertile Crescent most probably predates other regions in the appearance of intestinal parasitic infection. It is, therefore, not surprising that references to intestinal

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parasites appear in ancient regional texts (e.g., Papyrus Ebers, dated to ca. 1550 BC ; Hoeppli, 1956).

A 2019–2020 salvage excavation at Armon Hanatziv (south Jerusalem) exposed an estate with extraordinary architectural elements. Ya'akov Billig of the Israel Antiquity Authority directed the excavation. Based on a preliminary pollen investigation (conducted by DL), adjacent to the estate was a garden of fruit trees and ornamental plants (Fig. 1). During excavation of the garden area, a few installations were revealed, including a large water reservoir and a cubical stone object with a perforated hole in its center interpreted as a stone toilet seat (Billig et al., 2021; Fig. 2). This installation and associated sediments at its base are the focus of this study.

In Hebrew, the name of the site, Armon Hanatziv, means the Commissioner's Palace. The site is also known as the British Mandate Governor's House. The monumental structure uncovered included rare stone artifacts made of soft limestone with decorative carvings. The collection is composed of three complete, medium-sized stone capitals in the architectural style known as 'Proto-Aeolian' and items from lavish window frames and balustrades made of stylish columns on which a series of Proto-Aeolian style capitals of a tiny size were affixed. The level of workmanship on these capitals is the most expert seen to date in ancient Israel, and their excellent degree of preservation is rare (Billig, 2021). Based on ceramic typology, the site was dated to the mid-7th century BC (Billig et al., 2021), probably in the period between the reigns of King Hezekiah and King Josiah when Jerusalem was restored after the Assyrian siege of the city in 701 BC. The views from the ridge where Armon Hanatziv is situated are breathtaking: to the north, the City of David, and to the south, the Judean Desert. Jerusalem is located at the margins of the Mediterranean vegetation zone. During the investigated period, the region enjoyed the same climate as it does today (Kagan et al., 2015; Langgut et al., 2015; Finkelstein and Langgut, 2018; Palmisano et al., 2019).

The dimensions of the cubical stone object found in the garden and suggested as a stone toilet seat are: 53 × 49×35 cm. Current archaeological evidence of toilets in ancient Israel is limited. The earliest findings are dated to the Late Bronze Age and derive from three sites: a

Fig. 2. The stone toilet seat found during the 2019 excavation at Armon Hanatziv. Photo by Ya'akov Billig.

15–13th century BC cesspit from Tell el ʿAjjul (Petrie, 1932), a mid-14th century BC cesspit from Megiddo (Langgut et al., 2016), and, at Hazor, an *ex-situ* stone toilet seat and several cesspits connected by drains were found associated with Late Bronze Age strata (Fink, 2009: 169). In all three cases, the installations were located in palatial areas, indication of their use by members of ruling groups. Several stone toilet seats were exposed from Late Iron Age II Israel: a few in the City of David (Chapman, 1992; Shiloh, 1984; Steiner, 2001; De Groot and Bernick-Greenberg, 2012: 352), one near Ramat Rahel (Eisenberg and De Groot, 2006), and two in Lachish (Ganor and Kreimerman, 2019; Kleiman, 2020: Fig. 1). Pits associated with a drainage system were exposed in northern Israel (Ayyelet ha-Shahar), suggesting they were part of a toilet installation (Kletter and Zwickel, 2006). Unfortunately, only two archaeoparasitological studies were conducted at these toilet installations. Whereas at Megiddo's cesspit no parasite remains were

Fig. 1. Reconstruction of the toilet room that stood in the garden of the Armon Hanatziv royal estate. Drawing by Yaniv Korman.

found (Langgut et al., 2016), at Area E3 in the City of David, high concentrations of intestinal parasite eggs were recovered (Cahill et al., 1991).

During the excavation at Armon Hanatziv, several sediment samples associated with the stone toilet seat were collected for archaeoparasitological investigation. The study objectives were to provide information regarding the sanitary conditions of 7th century BC high-status residents of Jerusalem and to shed light on the history of diseases and epidemics in the region.

2. Materials and methods

Fifteen sediment samples were taken during the excavation using sterile equipment in order to prevent outside contamination. Eleven samples were recovered from various contexts associated with the stone toilet installation (samples nos. 1–11). Four additional samples were collected to serve as controls (samples nos. 12–15): three from the sediments on top and near the installation, and one sample from the surface sediment, 100 m east of the site.

During the extraction procedure, one *Lycopodium* spore tablet was added to each sample in order to determine parasite egg concentrations (following the method of pollen concentration estimations suggested by Stockmarr, 1971 and Maher, 1981). The chemical-physical treatment began with soaking the sediment samples in 10% HCl for one hour in order to remove the calcium carbonates within the sample, to loosen the different debris, and to dissolve the *Lycopodium* spores. Samples were then rinsed with distilled water several times until pH 7 was achieved. Next, a density separation was carried out using $ZnBr_2$ solution with a specific gravity of 1.95. After stirring well and vortex, samples were placed in an ultrasonic water bath for three minutes. After sonication, samples were centrifuged for 20 min at 3500 RPM (all other steps were followed by only five minutes of centrifuging with the same RPM). The floated suspension was then sieved through a 150 μm mesh screen and rinsed with distilled water. After rinsing the samples with ethanol, they were mounted in glycerin. The remains were identified under a light microscope at magnifications of 200X, 400X, and 1,000X (immersion oil). For each sample, all the extracted parasite eggs were counted and identified. The egg sizes were measured using an ocular micrometer with eggs randomly selected from all samples.

3. Results

Six archaeological samples were found to contain well-preserved parasite eggs from four taxa (in decreasing order; Table 1 and Fig. 3): *Ascaris lumbricoides* (roundworm), *Trichuris trichiura* (whipworm), *Taenia* sp. (beef/pork tapeworm), and *Enterobius vermicularis* (pinworm). The highest parasite egg concentrations were recorded for sample no. 5, which was taken from just below the stone toilet installation at its southwestern corner. No parasite egg remains were found in the four control samples (nos. 12–15). This result ruled out possible contamination by parasite eggs from the outside.

The measurements (length and widths) of the egg taxa are: *Ascaris lumbricoides* mean egg size 55.4 × 43.2 μm (n = 92, SD=5.9 ×7.0); *Taenia* sp. mean egg size 35.3 × 33.8 μm (n = 43, SD=4.3 ×4.8) and *Trichuris trichiura* mean egg size 50.3 × 23.9 μm (n = 23, SD=2.7 ×2.3). Two *Trichuris* eggs were found to be significantly larger (52 ×31 and 50 ×33) and likely belong to *T. suis* (Fig. 3c) based on the measurements given by Kumm et al. (2010: table 2). Due to the low numbers of this taxon identified in the Armon Hanatziv assemblages, *T. suis* are not presented in Table 1 and will not be discussed further. Only four *Enterobius vermicularis* eggs were measured. The eggs ranged in length from 47 to 56 μm and in width from 22 to 30 μm. No significant variation in egg size could be identified between the different samples.

Table 1
Parasite eggs recovered from Armon Hanatziv excavation (Jerusalem).

Laboratory ID	1 p/p	2 p/p	3 p/p	4 p/p	5 p/p	6 p/p	7 p/p	8 p/p	9 p/p	10 p/p	11 p/p	12 p/p	13 p/p	14 p/p	15 p/p
Field ID	Northeast below toilet seat L67 B1223/2	Northeast below toilet seat L67 B1223/1	Southwest below toilet seat L67 B1224/1	Inside the tunnel (A) L65	Southwest below toilet seat L67 B1224/3	Northeast below toilet seat L67 B1223/3	Inside the tunnel L66	Southwest below toilet seat L67 B1224/2	Inside the tunnel (B) L65	Lower gray stratum L67 B1248/1	Lowermost stratum, on top of bedrock (white) L67 B1248/2	Control, upper section, 40 cm above toilet seat	Control, above toilet seat, 1 cm above toilet seat	Control, between cover stones, near toilet seat	Control, surface sediments (=recent)
Ascaris lumbricoides	22	21	44		345	317				29					
Concentrations (g/sediment)	228.8	112.5	82.2		596.8	490.0				514.8					
Taenia sp.	5	7	6		11	14				1					
Concentrations (g/sediment)	52.0	37.5	11.2		19.0	21.6				17.8					
Trichuris trichiura	1	1			19	10				1					
Concentrations (g/sediment)	10.4	5.4			32.9	15.5				17.8					
Enterobius vermicularis	1	1	5		4	1									
Concentrations (g/sediment)	10.4	5.4	9.3		6.9	1.5									
Total parasite sum	29	30	55	0	379	342	0	0	0	31	0	0	0	0	0
Lycopodium	169	328	941	197	1016	1137	331	35	359	99	121	314	329	313	45
Sample weight (g)	6.5	6.5	6.5	6.5	6.5	6.5	7.0	7.0	6.5	5.2	5.2	5.5	5.7	5.8	4.9

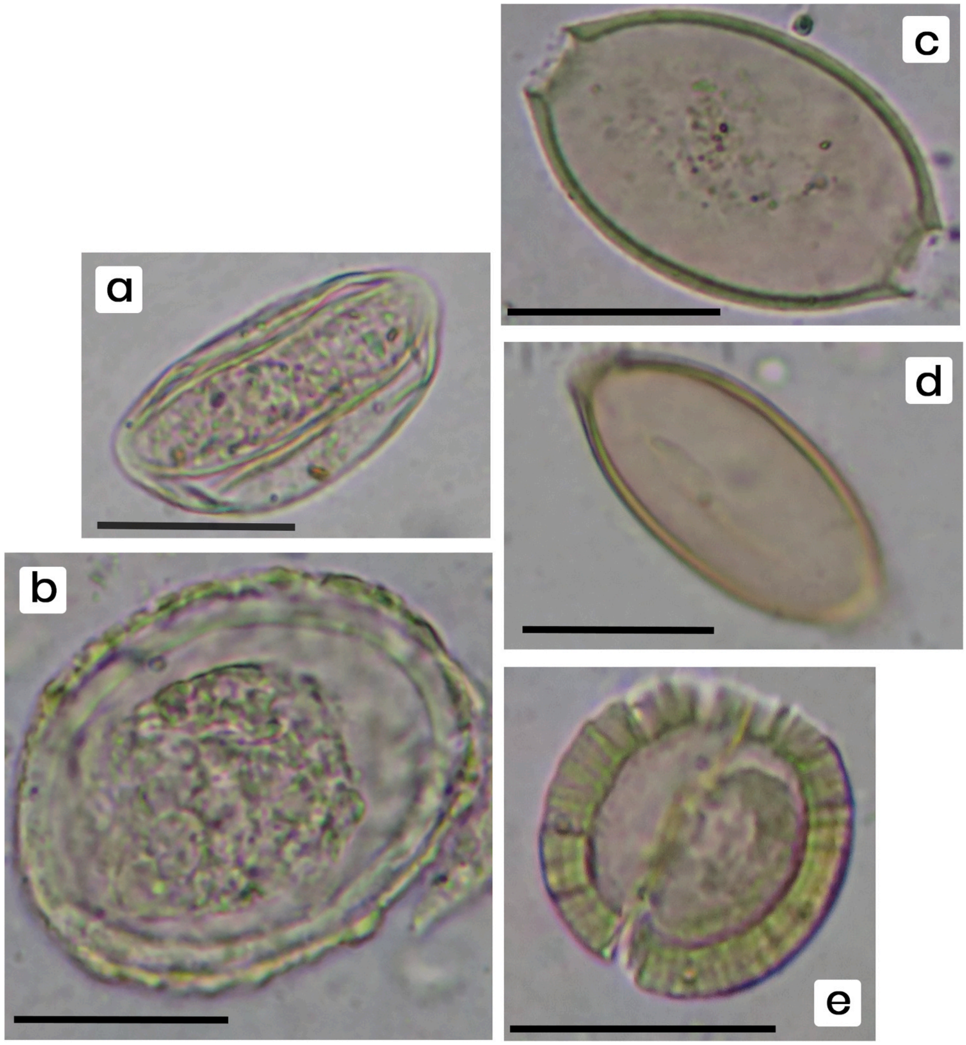

Fig. 3. Intestinal parasite eggs recovered from sediment collected below the stone toilet seat at Armon Hanatziv. (a). *Enterobius vermicularis*; (b). *Ascaris lumbricoides*; (c). *Trichuris suis*; (d). *Trichuris trichiura*; (e). *Taenia* sp. Each bar = 25 μm. Photos by Eitan Kremer and Sasha Flit (magnification X400).

4. Discussion

The two largest taxa in the Armon Hanatziv assemblage, roundworm (*Ascaris lumbricoides*) and whipworm (*Trichuris trichiura*), often contribute to malnutrition and to childhood stunting resulting from heavy infections (Fig. 3b and d). Both taxa have a fecal-oral transmission. They are common in conditions of limited sanitation and/or poor hygiene, where inadequate disposal of fecal material, contamination of food and water supplies with fecal waste, and the use of human feces as field fertilizer are prevalent (Nematian et al., 2008; Dent and Kazura, 2011; Oliveira et al., 2015). The beef/pork tapeworm *Taenia* sp. causes moderate infections such as abdominal pain, nausea, and diarrhea. It requires cattle or swine as intermediate hosts to complete its life cycle and is transmitted to the definitive human host through the consumption of raw, salted, dried, smoked, or poorly cooked beef and pork (Wittner et al., 2011: 839). The eggs of the parasite *Enterobius vermicularis* appeared in the lowest frequencies throughout the assemblage. The low ratios may stem from preservation issues. The eggs of this pinworm are particularly fragile and easily deformed or lost completely from archaeological samples (Reinhard and de Araújo, 2014). Their presence in the Armon Hanatziv record, though in small numbers, indicates a relatively good state of preservation (Fig. 3a). Pinworms are spread by fecal contamination of the hands or by airborne transmission and cause intense anal itching at night (Mitchell, 2017).

It is possible that as early as the 7th century BC, human feces were collected systematically from the city of Jerusalem in order to fertilize crops grown in the nearby fields. During the 7th century BC, when Judea was under Assyrian rule, the hinterlands of Jerusalem, especially to the west, shifted to specialized agriculture (versus mixed Mediterranean agriculture; Finkelstein et al., 2021; Langgut and Gadot, in press). The inhabitants were forced to farm inhospitable rock terrain and were told which type of crop to grow. Additionally, the type of fertilizer used might also have been dictated by the Assyrian economy. Modern research has demonstrated that human fecal fertilizer increases crop yields (Heinonen-Tanski and van Wijk-Sebesma, 2005). However, unless the feces are composted for many months before being added to the fields, viable parasite eggs can spread to the plants grown (e.g., Phuc et al., 2006). Hence, the use of human feces as crop fertilizer under the specialized Assyrian economy may have led to a growth in whipworm and roundworm. The almost total lack of sanitation technologies may also have been the primary trigger for parasite distribution in ancient Israel. The presence of tapeworm eggs attests to the consumption of poorly cooked, perhaps raw, beef or pork, the only meats that carry this parasite.

A limited number of studies to detect the presence of abdominal parasites in an archaeological context have been executed in Israel (Table 2). These studies identified whipworm (*Trichuris trichiura*) in most of the investigated sites: Jerusalem (7–6th century BC; Cahill et al.,

Table 2
Human abdominal parasite remains in ancient Israel (in chronological order).

Site	Age	*Ascaris lumbricoides*	*Taenia* sp.	*Trichuris trichiura*	*Enterobius vermicularis*	*Diphyllobothrium latum*	*Echinococcus granulosus*	*Entamoeba histolytica*	*Giardia duodenalis*	Reference
Armon Hanatziv (Jerusalem)	Mid-7th Century BC	+	+	+	+					This study
Beit Ahiel, City of David (Jerusalem)	7–6 Century BC		+	+						Cahill et al., 1991
Qumran	1st century BC – 1ST Century AD	+	+	+	+					Harter et al., 2004; Zias et al., 2006
Nahal Mishmar	2nd Century AD			+				+	+	Witenburg, 1961[a]
Jerusalem	1st century BC – 1ST Century AD						+			Zias, 1991
Acre	12–13th Century AD	+	+	+		+		+	+	Mitchell and Tepper, 2007; Mitchell et al., 2008

[a] We cannot be sure that Witenberg (1961) accurately described *Entamoeba* and *Giardia* in his paper, since he did not present images of these parasites.

1991), Qumran (1st century BC – 1st century AD; Harter et al., 2004; Zias et al., 2006), Nahal Mishmar (2nd century AD; Witenberg, 1961; Harter et al., 2004), and Acre (13th century AD; Mitchell and Tepper, 2007; Mitchell et al., 2008). Roundworm (*Ascaris lumbricoides*) was identified in Acre as well as at Qumran. The beef/pork tapeworm *Taenia* sp. was found in the aforementioned assemblages from Jerusalem, Qumran, and Acre. Pinworm eggs of *Enterobius vermicularis* were also revealed at Qumran (Zias et al., 2006). Significantly, the findings of roundworms and pinworms at Armon Hanatziv are the earliest on record for ancient Israel. The presence of pinworm does not necessarily indicate the earliest appearance in the region, since the occurrence of these delicate eggs is most probably related to the extraordinary state of preservation of organic material in the Armon Hanatziv cesspit deposits. Often, organic matter (pollen, seeds, parasite eggs) is relatively well preserved in cesspits due to mineralization processes (McCobb et al., 2001; Amichay et al., 2019; Dunseth et al., 2019).

The presence of the toilet installation in the garden of the magnificent Armon Hanatziv estate is not surprising. These rare facilities in the archaeological record of ancient Israel, when found, are usually in or adjacent to residences of high-status groups (e.g., Langgut et al., 2016). Sometimes they appear in religious or cultic contexts. For example, possibly the earliest toilet of record, comprising a deep cylindrical pit in a small room, was excavated in a building in the religious complex of the city of Uruk, dating to ca. 3200 BCE (McMahon, 2015: 22).

The occurrence of intestinal parasite eggs in the Armon Hanatziv cesspit indicates that the toilet was most probably a quite primitive installation, increasing risk of exposure to parasites and parasite-related diseases and epidemics. It is also possible that other sanitary practices of those using the toilet were either poor or non-existent and a contributing or primary factor in the spread of parasite-related diseases. The toilet seat was made of a single large block of limestone. It resembles its modern-day counterparts except for its lack of plumbing. The toilet installation was probably located in a small-ventilated room in the garden (Fig. 1). The presence of airborne pollen such as pine at the cesspit deposits (preliminary results from palynological investigation conducted by DL) may suggest that the room was either equipped with windows, or was roofless. It is also possible that the pine was used to help cover the smell like in modern compost toilets.

The purpose of archaeoparasitological research is not only to extend our knowledge of disease patterns in a particular region. These types of studies also provide evidence to assist in answering archaeological questions. For example, the identification of the Armon Hanatziv cesspit deposits just below the stone seat toilet indicates that the latter was in situ. The identification also helps determine the exact use of such installations. The Iron Age II find from Lachish, for example, has recently generated a debate. Ganor and Kreimerman (2019) interpreted the object as a toilet seat, whereas Klieman (2020) suggested that the cubical perforated stone artifact was used for cultic purposes.

5. Summary

The archaeoparasitological analysis conducted at the extraordinary Late Iron Age estate of Armon Hanatziv sheds new light on the history of diseases and epidemics during the mid-7th century BC in Jerusalem. To date, this is among the earliest evidence of parasite remains in ancient Israel. Four taxa of intestinal egg parasites were recovered from the sediments below the in-situ stone toilet seat: roundworm (*Ascaris lumbricoides*), whipworm (*Trichuris trichiura*), beef/pork tapeworm (*Taenia* sp.), and pinworm (*Enterobius vermicularis*). The presence of the latter points to the good state of preservation of the cesspit deposits since the relatively delicate pinworm eggs generally do not survive in such contexts.

While the mere existence of something as rare as a toilet installation seems to indicate that at least some ancient Jerusalemites enjoyed a relatively high level of sanitation, the evidence of intestinal parasite eggs suggests just the opposite. The presence of indoor toilets may have been more a matter of convenience than an attempt to improve personal hygiene. A toilet was a symbol of wealth, a private installation that only the rich could have afforded.

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