A comparison of ancient parasites as seen from archeological contexts and early medical texts in China

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\textbf{ABSTRACT}

This paper integrates our knowledge from traditional Chinese medical texts and archeological findings to discuss parasitic loads in early China. Many studies have documented that several different species of eukaryotic endoparasites were present in early human populations throughout China. Nevertheless, comprehensive paleoparasitological records from China are patchy, largely due to taphonomic and environmental factors. An examination of early Chinese medical texts allows us to fill in some of the gaps and counteract apparent biases in the current archeoparasitological records. By integrating the findings of paleoparasitology with historic textual sources, we show that parasites have been affecting the lives of humans in China since ancient times. We discuss the presence and prevalence of three groups of parasites in ancient China: roundworm (\textit{Ascaris lumbricoides}), Asian schistosoma (\textit{Schistosoma japonicum}), and tapeworm (\textit{Taenia} sp.). We also examine possible factors that favored the spread of these endoparasites among early humans. Therefore, this paper not only aims to reveal how humans have been affected by endoparasites, but also addresses how early medical knowledge developed to cope with the parasitic diseases.

\textbf{中文摘要}

随着考古遗存中古代寄生虫样本发现的增多，古代寄生虫研究成为了学术界的一大关注点。与此同时，中国考古遗存中发现的古代寄生虫样本也证实了古代先民曾受到寄生虫病的侵扰。但是由于保存环境、虫卵的生理特征等方面因素的限制，古代寄生虫在考古遗存中的发现仍然较为少见。因此，除过考古学报道及古代寄生虫学的相关研究，古代医学及历史文献成为了我们了解过去寄生虫及寄生虫病的重要参考材料。本文通过对相关文献的梳理，重点关注并讨论蛔虫、绦虫以及日本血吸虫这三种肠道寄生虫在中国古代的分布及感染状况。除此之外，本文将重点讨论这些肠道寄生虫的途径以及其背后的深层原因。本文旨在通过整理古代居民感染寄生虫的途径，结合考古学发现及医学文献的记载，进一步了解古代居民关于寄生虫及寄生虫病的认知与了解的发展进程。

\textbf{1. Introduction}

The study of parasites in early human populations, known as paleoparasitology, is the practice of examining parasites from ancient materials such as coprolites, latrines, cesspools, soil samples from human burials, and mummified remains (Le Bailly et al., 2012; Reinhard, 1986; Yeh et al., 2016; Yeh and Mitchell, 2016). It provides an insight into the lives of past humans – their health, their diets and cooking practices, their migration patterns, and their attempts at hygiene. Paleoparasitology faces practical challenges, poor preservation in particular, that has resulted in a scarcity of findings in regions of the world such as Southeast Asia (Yeh et al., 2016). Lack of awareness of the importance of collecting abdominal soil samples during excavation and/or the inability of excavation staff to recognize coprolites poses additional challenges to paleoparasitological inquiry. These factors affect the likelihood of recovering the eggs of ancient parasites. As a consequence, archeological sites in China have produced only a handful of discoveries in the field of paleoparasitology, with most ancient parasites acquired from mummies (Yeh and Mitchell, 2016).

This paucity of data on early parasites reflects a lack of attention given to the field of paleoparasitology as compared to the field of general bioarcheology in China and certainly should not be taken as indicative of low parasitic loads in past populations. Indeed, early medical texts and other historic sources frequently mention parasites. At this juncture, it seems advisable to couple recognized evidence from ancient medical texts, which clearly show the presence of parasites in ancient human populations, with the few actual archeological finds of parasites. With this idea in mind,
we have examined some ancient medical texts such as Zhu Bing Yuan Hou Lun (Treatise on the Causes and Manifestations of Diseases), Jin Gui Yao Lue (Essential Prescriptions from the Golden Cabinet), Jing Yue Quan Shu (Jingyue's Complete Works), and Tai Wei Mi Yao Fang (Arcane Medical Essentials from the Imperial Library). This analysis has allowed us to expand our knowledge of parasites in early Chinese society and their impact on human health. Several groups of parasites are clearly mentioned in the ancient Chinese medical texts, including roundworms, tapeworms, blood flukes, intestinal flukes, hookworms, and head lice. In this paper, we focus on three groups of endoparasites because they tend to cause easily identifiable symptoms and result in notable pathological features visible on the remains of affected individuals. The groups we studied are roundworms (Ascaris lumbricoides), Asian schistosomiasis (Schistosoma japonicum), and tapeworms (Taenia sp.). By performing a systematic bibliographic search on findings of parasites in early China, not only do we gain a detailed understanding of paleoparasitology in China, but we also begin an exploration of how parasites have affected the lives of the people in the past, how humans coped with disease, and how illnesses caused by parasitic infections were treated.

2. Materials and methods

Archaeological reports, medical texts, meeting abstracts, and other related resources are included for analysis in this study. The 40 references introduced include (a) archaological findings of Ascaris lumbricoides, Schistosoma japonicum, and Taenia sp. in China; (b) early Chinese medical texts that mention parasites, symptoms of parasitic infections, or describe the related treatments; (c) historical records dating back to the 19th century AD or before. Our overview of sources is not limited to mainland China, but also encompasses the record of other East Asian countries, such as Japan and Korea, in order to facilitate discussion on the prevalence of Asian Schistosoma and tapeworms in East Asian archeological sites.

From the materials chosen for our study, the following data were collected: (a) the geographic location of archeological sites where parasitic eggs have been identified; (b) the date of each find; (c) the types of specimens gathered from loci where parasitic eggs have been collected such as hygiene sticks, coprolites, sediment, and other materials; (d) the treatments used to eliminate parasitic infections; and (e) the description of parasites and related symptoms after infection. These findings are summarized in Table 1 and Fig. 1. Additionally, we discuss the details of each species studied in archeological and medical contexts below.

3. Results: The physical evidence for some specific parasites in ancient China

3.1. Roundworm (Ascaris lumbricoides)

Ascaris lumbricoides, commonly referred to roundworm, has been documented in early human communities throughout the world and remains common today. Ascariasis results from infection with this particular parasite, which affects approximately one-sixth of the human population today (Harhay et al., 2010). Roundworms can be spread through fecal-oral transmission, most often promoted by poor hygiene and the mishandling of food, thereby facilitating fecal contamination. The unique morphological characteristics of the roundworm egg include a characteristic oval-shape, which along with a mamillated coat, make it easy to identify through low power microscopic observation (Schmidt and Roberts, 2006).

In humans suffering from ascariasis, roundworm eggs hatch in the duodenum and develop into larvae. These larvae then develop into adult worms while traveling to the liver, lungs, heart, and other organs, finally returning to the small intestine (Schmidt and Roberts, 2006). In extreme cases of ascariasis, symptoms may include vomiting (Margery and Nyang, 2011), and at this level of involvement, ascariasis can even lead to death as a result of intestinal obstruction (De Silva et al., 1997). The symptoms of ascariasis are also exacerbated when worms migrate to passageways leading to the biliary tract and pancreatic duct, a condition known as biliary ascariasis (Khuroo et al., 2016). In children, ascariasis has been reported to delay cognitive development and cause cognitive impairment (Schmidt and Roberts, 2006). Nevertheless, the majority of ascariasis cases are not fatal and may be accompanied only by fairly mild symptoms or even remain asymptomatic.

3.1.1. Archeological findings of roundworm

Roundworm is a common parasitic species found in archeological contexts (e.g., Le Bailly et al., 2014; Leles et al., 2010; Mitchell, 2013; Reinhard and Araújo, 2012; Shin et al., 2015; Yeh et al., 2014). In modern fecal samples, the A. lumbricoides egg is easily identified by the characteristic mamillated coat found on the outer layer of the intact egg. Unfortunately, this identifier is often destroyed by taphonomic processes and is

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**Table 1**

Selected ancient medical books recording parasitic and related diseases in ancient China.

<table>
<thead>
<tr>
<th>Name</th>
<th>Author</th>
<th>Date</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huangdi Neijing</td>
<td>Authors unknown</td>
<td>Most of the text completed during the Warring States Period (5th C BC to 221 BC); some completed during the Western Han Dynasty (202 BC-AD 8) without accurate dates</td>
<td>Two parts: Suwen (素问) and Lingshu (灵枢)</td>
</tr>
<tr>
<td>Jin Gui Yao Lue</td>
<td>Zhang Zhongjing 张仲景 (also known as Zhang Ji 张机) (AD 150-219)</td>
<td>Shang Han Za Bing Lun 傅寒杂病论 probably finished around AD 200-210 (Eastern Han Dynasty AD 25-220)</td>
<td>A part of Shang Han Za Bing Lun 傅寒杂病论</td>
</tr>
<tr>
<td>Zhou Hou Fang</td>
<td>Ge Hong 葛洪 (AD 283/284-343/364)</td>
<td>The accurate completion date of this book remained unknown (Eastern Jin Dynasty AD 317-420)</td>
<td>Also known as Zhou Hou Bei Ji Fang 薛后备急方</td>
</tr>
<tr>
<td>Zhou Bing Yuan Hou</td>
<td>Chao Yuanfang 章元方 (active in AD 605-616)</td>
<td>Written in AD 610 (Sui Dynasty AD 581-618)</td>
<td>Also known as Chao Shi Bing Yuan 章氏病源 or Zhou Bing Yuan Hou Zong Lun 薛氏病原论</td>
</tr>
<tr>
<td>Qian Jin Fang 千金方</td>
<td>Sun Simiao 孙思邈 (AD 541/581-682)</td>
<td>Completed around AD 652 (Tang Dynasty AD 618-907)</td>
<td>Also known as Bei Ji Qian Jin Yao Fang 白帝千金药方 or Qian Jin Yao Fang 千金药方</td>
</tr>
<tr>
<td>Wai Tai Mi Yao Fang</td>
<td>Wang Tao 王焘 (AD 670-AD 755)</td>
<td>Completed around AD 752 (Tang Dynasty AD 618-907)</td>
<td>Also known as Wai Tai Mi Yao 外台秘要</td>
</tr>
<tr>
<td>Bianque Xin Shu</td>
<td>Dou Cai 神医 (AD 1076-1146)</td>
<td>Completed around AD 1146 (Song Dynasty AD 960-1279)</td>
<td></td>
</tr>
<tr>
<td>Ru Men Shi Qin</td>
<td>Zhang Congzheng 张从正 (AD 1156-1228)</td>
<td>Completed around AD 1228 (Jin Dynasty AD 1115-1234)</td>
<td></td>
</tr>
<tr>
<td>Yin Shi Xu Zhi</td>
<td>Jia Ming 贾明 (AD 1269-1374)</td>
<td>The accurate completion date of this book remained unknown (Yuan Dynasty AD 1271-1368)</td>
<td></td>
</tr>
<tr>
<td>Jing Yue Quan Shu</td>
<td>Zhang Jiebin 张介宾 (AD 1563-1640)</td>
<td>The accurate completion date of this book remained unknown (Ming Dynasty AD 1368-1644)</td>
<td></td>
</tr>
</tbody>
</table>
missing in most archeological samples (Bouchet et al., 2003). However, in mainland China, reports from archeological sites regularly mention the discovery of roundworm eggs. Lei and Hu (1984) and Yang et al. (1984) reported that a female mummy dating back to the Warring States Period (471–221 BC), exhumed from the Jiangling site in Hubei Province, had roundworm eggs inside her corpse. Zhang et al. (2006, 1999) examined the sediment samples from human burials at the Jiahu site in Henan Province, dating back to the Neolithic Peiligang culture (7000–5700 BC), and reported the presence of roundworm eggs. However, it was later noted that these finds were controversial, as the parasitic eggs did not conform to the typical dimensions of roundworm eggs found in modern humans (Yeh and Mitchell, 2016). In 2012, Wei et al. published a study in which the pelvic soil taken from 20 burials at Zhengzhou, in Henan Province, dating back to the Zhou dynasty’s Spring and Autumn Period (770/771–476/403 BC) was carefully sifted and examined. From these 20 burials, 18 fertilized and 16 unfertilized roundworm eggs were identified. In 2016, roundworm eggs were identified on latrine sticks recovered at the Xuanquanzhi (悬泉置) relay station. This latrine, built in 111 BC, was frequented by travelers along the Silk Road as they traveled past Dunhuang in Gansu Province, northwest China. It stopped being used sometime in AD 109. Xuanquanzhi offered accommodation to travelers and acted as a place where government officials and riders from the postal service could change horses (Yeh et al., 2016).

3.1.2. *Ascaris* in ancient Chinese medical texts

*Chong* (虫) is a character that collectively refers to large terrestrial invertebrates, such as insects and worms, in Mandarin Chinese. This character is often included as a part of the specific names of parasites. Early Chinese medical texts often mention *chong* and different types of *chong* in association with symptoms typical of ascariasis. There are several different character combinations that denote roundworms in the historic texts, including *hui* (蛔), *hui chong* (蛔虫) or *jiao hui* (蛟蚘). This was noted in *Zhu Bing Yuan Hou Lun*, a medical text compiled by Chao Yuanfang (巢元方). Chao Yuanfang was an imperial physician during the Sui Dynasty (AD 581–619) and actively participated in his career around AD 605–616. He described patients suffering from abdominal swelling and pain, and chest pains, as well as drooling and vomiting of a water-like liquid (Chao, [1982]). These symptoms have recently been interpreted as indicative of intestinal obstruction related to ascariasis (Jiang, 1993).

The earliest possible record of ascariasis in ancient China can be found from *Su Wen, Huangdi Neijing* (素问, 黄帝内经):

“The symptom of stomach-caused coughing is vomiting after coughing; and severe coughing would lead to vomiting long worms out (胃咳之状, 咳而呕, 呕甚则长虫出) (Wei ke zhi zhuang, ke er ou, ou shen ze chang chong chu).”

The author(s) of *Su Wen, Huangdi Neijing* remains unknown. It is believed that this book dates back to the time between the Warring States Period (475–221 BC) and the Han Dynasty (206 BC to AD 220).

Other medical texts describing the presence of ascariasis and its symptoms include *Shang Han Za Bing Lun* (伤寒杂病论), written by Zhang Zhongjing (张仲景) completed around AD 200–210. Zhang Zhongjing was a practical physician with great reputations during the late East Han Dynasty (AD 189–220). This text described *jue yin* (厥阴), a disease that caused the patient to feel thirsty despite drinking abnormally large quantities of water:

“The patient would also experience uncomfortableness in the thoracic region and burning inside the stomach. The patient would not have the appetite to eat though hungry; after eating, the patient would suffer from vomiting roundworms (厥阴之为病, 消渴, 气上撞心, 心中疼痛, 饥而不欲食, 食则吐蚘 (蛔), 下之利不止).”

*Jing Yue Quan Shu*, written by Zhang Jiebin (张介宾), a Ming-Dynasty physician living in AD 1563–1640, stated that:

“Having weak ‘Qi’ (气) in internal organs is the ultimate reason why...”
patients grow parasites in them... In that case, be it damp-heat body constitution, raw and cold food, sweet and fatty food or greasy food that causes indigestion, can all cause parasites to grow (虫能为患者, 终是脏气之弱...然则或由湿热, 或由生冷, 或由肥甘, 或因滞腻, 皆可生虫).” In Zhou Hou Fang (肘后方), which was completed during the Eastern Jin Dynasty (AD 317–420) without an actual date, Ge Hong (葛洪) stated that he believed everyone had intestinal parasites during his time (Ge, 1983). Ge Hong was an Eastern Jin Dynasty scholar with great knowledge in medicine and alchemy.

Later on, a scholar named Kong Wuzhong (孔武仲) from the Song Dynasty proposed that enterobiasis and ascariasis were the most prevalent parasitic diseases in China (Kong et al., 2002):

“Lice and fleas bother people while pinworms and roundworms grow inside of people. These seem to be carried from birth to death, not occasional infection (外有蚤虱, 内有蛲、蛔, 盖与生以终始, 非有时而来袭).” Kong Wuzhong also noted the frequent recurrence of ascariasis infestations (Hsiao, 2000).

Given this high rate of parasite infestation, many ancient Chinese medical practitioners developed considerable and detailed knowledge of the routes of infection and learned how to prepare practical remedies for eliminating roundworms. Jing Yue Quan Shu highlighted that consumption of raw food frequently led to roundworm infection (Zhang, 1994). In a bid to expel the roundworms and soothe the accompanying abdominal pain, ancient medical practitioners used the leaves of wu ju (吴萸), a traditional name referring to the large-fruited elm (Ulmus macrocarpa), as well as many different ferns, referred to as guan zhong (贯众), including Dryopteris crassirhizoma, Woodwardia unigemmata, Osmunda japonica, and Matteuccia struthiopteris. The Chinese honey-suckle or Rangoon creeper (Quisqualis indica), mentioned in texts as shi jun zi (使君子) and Carpesium abrotanoides, referred to as he shi ((spanish)) were other common deworming treatments (Sun and Zhao, 2007).

3.2. Asian schistosoma (Schistosoma japonicum)

Schistosoma is a parasitic flatworm that infects humans causing schistosomiasis, a disease which is frequently found in mainland China and the Philippines. There are five different species of this worm, namely: Schistosoma mansoni, S. japonicum, S. mekongi, S. intercalatum, and S. haematobium. S. japonicum (You and McManus, 2015). The life cycle of schistosomes is complex, as they go through remarkable morphological transformations and experience changes in cellular composition, as well as exploiting several intermediate hosts. Their eggs are introduced to freshwater via the urine or feces of mammalian hosts. The eggs hatch to release miracidia that penetrate snails and eventually mature to cercariae. When these leave the host snails and are released into open water they already have the capacity to breach the skin of any potential mammalian host they encounter and then mature into reproductively capable adult worms infesting the bloodstream of the affected mammals (Gobert et al., 2009; Gryseels et al., 2006).

Humans contract schistosomes when they come into contact with freshwater infested by cercariae (Gobert et al., 2009). Free-swimming cercariae penetrate the skin and release schistosomula that enter the lungs through the capillaries and lymphatic vessels (Gobert et al., 2009). After maturing in the portal venous system, adult worms of S. japonicum and S. mansoni migrate to the veins of the intestines, while in the case of S. haematobium adult worms, they migrate to the venous plexus of the bladder, and these eggs are passed again in the urine (Gobert et al., 2009). Once infected, the human host displays a range of symptoms, including fever, exhaustion, diarrhea, and coughing (Gray et al., 2011; Zhou et al., 2009). If the infection is not managed promptly, it increases the risk of the disease developing into a series of other illnesses affecting the gastrointestinal tract or liver and prompting neurological issues (Gray et al., 2011). Human schistosomiasis remains a serious health issue in China, even though there has been an ongoing campaign to eradicate the disease for the last 50 years. Nonetheless, 30 million Chinese are still at risk of developing diseases that result from being infected by S. japonicum (Zhou et al., 2005).

3.2.1. Archeological findings of Asian Schistosoma

Wei (1973) examined a female mummy from the Mawangdui tomb, located at Changsha, which dates back to the Han dynasty (206/202 BC–AD 220) and was exhumed in 1970. Upon examination, it was found that the mummy contained eggs characteristic of Asian schistosoma. In 1981, Wei et al. carried out a study which looked at a Han dynasty mummy from Phoenix Hill, in Hubei Province. This investigation also revealed the presence of Asian schistosoma in the mummy (Wei et al., 1981). Expanding the scope of our considerations to the rest of East Asia, S. japonicum was identified in Japan in the early 20th century, but was eradicated later (Tanaka and Tsuji, 1997). There have been no paleoparasitological findings of S. japonicum in Japan thus far. Similarly, there have been no documented archeological finds of S. japonicum in South Korea, reported in the pertinent literature (Lee et al., 2011; Kim et al., 2016; Seo et al., 2014, 2007; Shin et al., 2017, 2009).

The general trend seems to be that in most regions of East Asia, Asian Schistosoma is rarely reported in archeological sites. Two factors could explain the apparent scarcity of Schistosoma in early China. First and foremost, there has been a dearth of research focused on paleoparasitology in this part of the world and identifying such parasites is also not straightforward. Second, poor preservation could also be a factor due to the fragility of the Schistosoma species’ eggs. These eggs have thinner cell walls than those of roundworms and whipworms.

3.2.2. Asian schistosomiasis in early Chinese medical texts

Many early medical texts mention gu (蛊), a written character that refers to a worm inside the body. The symptoms of gu described in these texts include extreme pain in the hands and legs, chest pain, expectation of blood, abdominal swelling, and severe anemia. Though it cannot be confirmed that these symptoms were caused by blood flukes, some features of gu are similar to those of schistosomiasis (Jiang, 1993; Xiao, 2006). Jiang (1993) interpreted related descriptions appearing in Zhu Bing Yuan Hou Lun as characteristic of schistosomiasis. Jiang also pointed out that reports of the presence of such infections can be narrowed down to a few geographical areas. The cause, symptoms, and diagnoses of the infection were also recorded (Jiang, 1993). Zhu Bing Yuan Hou Lun, states that the disease was prevalent in the lower reaches of the Yangtze River, especially near water sources (Chao, [1982]):

“In San Wu regions (commonly referred as the lower reaches of the Yangtze River) and southward, shui du bing (water-caused disease, 水毒病) was prevalent near the sources of river streams. Residents near there were easily get infected by this disease during springs and falls (自三吴以东及南诸山郡山, 有山谷溪源处有水毒病, 非秋毒得).”

The shui du bing (water disease) recorded in Chao Yuanfang’s medical text is likely to have been schistosomiasis according to the information provided, as schistosomiasis had been very prevalent in the Yangtze River region until the 21st Century (Zhou et al., 2005). Furthermore, schistosomiasis most often occurs during the spring and fall. Additionally, the description of sha shi (沙虱) from Zhu Bing Yuan Hou Lun appears to be reminiscent of the cercarial dermatitis caused by blood flukes (Jiang, 1993). The early text from Zhu Bing Yuan Hou Lun described sha shi (沙虱) to be small and almost invisible to the naked eye. An unsuspecting human can catch the parasite easily when passing through contaminated waters even through activities like walking through the grass on a rainy day or when bathing (Chao, [1982]):

“The mountains and rivers are infested with sha shi (沙虱) which are so fine that they can hardly be seen. People would get attached on and infected with them by entering these rivers to bathe and walking among grasses on rainy days (山水间多有沙虱, 其细略不可见, 人入水浴及水澡浴, 此虫在水中, 著人身, 及阴天雨行草中, 亦著人, 便钻入皮里).”
Families of Cestodes that commonly infect humans as definitive hosts.

Table 2

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>Intermediate hosts</th>
<th>Geographic distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diphyllobothriidae</td>
<td>Diphyllobothrium latum (fish tapeworm)</td>
<td>First intermediate host: freshwater crustacean</td>
<td>Scandinavia, western Russia, and the Baltics. Also present in North America</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Second intermediate host: freshwater fish</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adenocephalus pacificus (fish tapeworm)</td>
<td>First intermediate host: freshwater crustacean</td>
<td>South America</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Second intermediate host: saltwater fish</td>
<td></td>
</tr>
<tr>
<td>Taeniidae</td>
<td>Taenia saginata (beef tapeworm)</td>
<td>Cattle</td>
<td>Africa and the Middle East</td>
</tr>
<tr>
<td></td>
<td>Ourasiatica (Asian tapeworm)</td>
<td>Pigs</td>
<td>East Asia and Southeast Asia</td>
</tr>
<tr>
<td></td>
<td>Taenia solium (pork tapeworm)</td>
<td>Primarily found in Pigs</td>
<td>Cosmopolitan</td>
</tr>
<tr>
<td>Hymenolepididae</td>
<td>Hymenolepis nana* (dwarf tapeworm)</td>
<td>Arthropods</td>
<td>Cosmopolitan (mainly temperate areas)</td>
</tr>
</tbody>
</table>

* Previously known as Taenia nana.

No cures for gu infection were known in early China, as suggested by the lack of remedies mentioned in the historic texts. Sun Simiao (孙思邈) was a famous imperial physician of the Sui and Tang Dynasties and he was titled as China’s King of Medicine. (Sun, [1955]) in Qian Jin Fang (千金方), recorded that a patient suffering from a severe case of edema might not be cured, and the illness would last a lifetime:

“Patients who suffer from edema may have swollen abdomens (which can be as hard as stones) and thin limbs. This is a life-long disease that cannot be cured with aggressive treatments (有人患水肿，腹大四肢细，腹坚如石……此终身不以为治)”.

Though it remains unknown whether blood fluxes caused the edema, it still gives us an indication that gu was not an infection that could be cured easily in early China. In general, traditional Chinese medicine appears to have had a limited understanding of schistosomiasis (Xiao, 2006).

3.3. Tapeworm (Taenia sp.)

Cestoda, also known as tapeworm, is a class of worms within the phylum Platyhelminthes. The life cycle of tapeworms is complex and tends to involve intermediate hosts (see Table 2). There is an abundance of Cestode species, many of which are capable of infecting humans, including Taenia sp., Diphyllobothrium latum and Hymenolepis nana (Choi et al., 2012; Muehlenbachs et al., 2015; Sato et al., 2018). We focus on Taenia sp. identified in archeological and medical contexts, because these worms are abundant and can be reliably identified based on the characteristics of their eggs. There are three species of Taenia that may use humans as their hosts: T. asiatica, T. solium, and T. saginata (Sato et al., 2018) (Table 2). Human infection with tapeworm is related to the consumption of raw or undercooked meat and/or the internal organs from other prior hosts. Pigs serve as hosts of T. asiatica and T. solium, while T. saginata infects cattle (Chao et al., 1979; Fan and Chung, 1998; Galán-Puchades and Fuentes, 2013a). The three species of the human-hosted Taenia have a relatively higher rate of infection in the regions where people routinely consume raw or undercooked pork and beef, which is a common practice in many communities of East and Southeast Asia (Ale et al., 2014; Eom et al., 2009; Ito et al., 2014). T. asiatica is a problematic taxon, as it presents a T. saginata-like morphology and a T. solium-like life cycle (Galán-Puchades and Fuentes, 2013a).

The eggs of all three Taenia species are indistinguishable from one another when relying solely on relatively low power light microscopy (Zeilbig, 2014). The adult worms of T. asiatica and T. saginata are also difficult to distinguish from one another solely through such routine microscopic observation (Fig. 2) (Eom, 2006). At this time, only the deployment of approaches using the identification of specific immunodiagnostic antigens can reliably distinguish T. solium from T. asiatica (Galán-Puchades and Fuentes, 2013a). A report of the most recent study by Sato et al. (2018) indicates that mtDNA markers can reliably distinguish among the three species of human tapeworms, T. solium, T. saginata, and T. asiatica. Interestingly, using nuclear gene markers, T. asiatica found in Laos was identified to be a hybrid descendant of T. saginata and T. asiatica (Sato et al., 2018). As molecular methods have not been widely applied in paleoparasitology to date, all three species of Taenia are usually simply referred to as Taenia sp. in order to avoid potential misdiagnoses and incorrect species assignment.

3.3.1. Archeological findings of tapeworms

Multiple paleoparasitological studies have identified tapeworms in association with the archeological sites of Imperial China (post 221 BC). Excavations of a latrine at the Xuanquanzhi site resulted in recovery of many cloth-covered sticks used for wiping the anus after defecation as a measure for personal hygiene. Some of the sticks were found to have remnants of dried feces still on the cloth, and subsequent analysis revealed the presence of Taenia sp. eggs in these samples (Yeh et al., 2016). A mummy from another Han dynasty site located in Phoenix Hill, Hubei Province, contained helminth eggs identified as Taenia sp. (Wei et al., 1981).

There have been few tapeworm cases reported from East Asian archeological contexts outside of China. Although paleoparasitological research has been carried out in South Korea for several decades, reports of tapeworms remain few in number. Instead, the common ancient parasites found in South Korea are whipworms (Trichuris trichiura), roundworms (A. lumbricoides), and Chinese liver flukes (Clonorchis sinensis) (e.g., Han, 2003; Seo et al., 2014, 2007; Shin et al., 2009). According to Lee et al. (2011), the first recorded identification of ancient Taeniid eggs in South Korea can be traced to the soil from around the pelvis of a mummy found in a 17th-century tomb. The other two reported paleoparasitological discoveries of Taenia sp. eggs in South Korea came from soil samples (Kim et al., 2016) and mummies (Shin et al., 2017), respectively.

In Japan, paleoparasitological research has been focused on analyses of ancient toilets and coprolites. From these samples, small numbers of tapeworm eggs have been found, likely indicative of undercooked beef or pork consumption (Matsui et al., 2003). Interestingly, it is believed that the early Taenia sp. found in Japan may be traced back to origins in China or Korea, given that there was limited consumption of meat in early Japan as compared to that in continental East Asia at the same time (Board of Education, Fukuoka City, 1993). Overall, tapeworms have rarely been found in archeological contexts in East Asia. This can be attributed to the low probability of identifying tapeworm infections or due to poor preservation (Lee et al., 2011).

3.3.2. Tapeworm in ancient Chinese medical texts

White worms (bai chong, 白虫 or cun bai chong, 寸白虫) are
repeatedly mentioned in early medical texts from China. The colors and features described in these texts closely match the known morphology of tapeworms. The term *white worms* appeared in ancient medical texts as early as AD 217 in *Jin Gui Yao Lue* written by Zhang Zhongjing from the Eastern Han Dynasty. *Zhu Bing Yuan Hou Lun* also recorded *cun bai* chong, describing the length of the worms as almost the same as an Iris leaf, with some growing even longer than that (Chao, [1982]):

"Cun Bai, one of the nine worms, is one inch long, white in color and small in size. It would start to hurt the host when the host’s intestinal organs are weak ([寸白者，九虫内之一虫也，长一寸而色白，形小蝙，因府藏虚弱而能发动])."

Ancient medical practitioners were aware of the probable causes of tapeworm infections. Zhang Zhongjing (AD 150–219) indicated that tapeworm infections might be caused by eating raw meat and drinking milk, or by eating pork and beef at the same time (Zhang, 1956):

"Eating sliced raw meat with dairy together would lead to the growth of worms in one’s intestinal system, which causes acute infectious disease ([食脍，饮奶酪，令人腹中生虫])."

Along the same lines, Chao Yuanfang noted in his book, *Zhu Bing Yuan Hou Lun* that eating dairy products after consuming raw fish could result in one acquiring tapeworms (Chao, [1982]). Many ancient medical practitioners noted that *white worm* causes weight loss when it invades a person’s body. By the time of the Han Dynasty, it was found that white worm infection was linked with eating meat, particularly beef that was either raw or undercooked. *Bianque Xin Shu* (扁鹊心书) (completed around AD 1146, written by the Song Dynasty physician Dou Cai) from the Song Dynasty (AD 960–1279) also noted that eating large amounts of beef could lead to contracting tapeworms (Dou, [2015]). As for the treatment, plant remedies based on *Torreya nucifera*, a coniferous tree referred to as *fei zi* (榧子), large-fruited elm (*Ulmus macrocarpa*) known as *wu yi* (芜荑), *Tetradium ruticarpum* with the traditional name of *wu zhu yu gen* (吴茱萸根), and *Areca catechu*, a palm tree from Asia and the Pacific referred to in texts as *bin lang* (槟榔), were employed for deworming humans infected with white worm (Sun and Zhao, 2007). Sun, in *Qin Jin Fang* even proposed the need for anthelmintic herbs that would allow the patient to remain in limosis, the state of morbid hunger, when taking medicine, as well as the need to get sufficient rest to expel the worms (Sun, [1955]). It was also suggested in *Jin Gui Yao Lue* that one should not consume beef, lamb, or pork cooked/steamed with elm or mulberry sauce in order to prevent oneself from being infected by the worms (Zhang, 1956). Although this early recommendation can be dismissed based on a modern medical perspective, it underscores a general awareness of ancient medical practitioners’ cognizance of the sources of *white worm* infection.

### 4. Discussion

The evidence from both ancient medical texts and archeological finds suggests a high prevalence of parasites and related parasitic diseases in ancient China. *Jiu chong* (九虫, nine different worms) (Fig. 3) had already been recorded in several ancient medical texts, with some of these being identified as roundworms, tapeworms, pinworms, intestinal flukes, blood flukes, and head lice (Jiang, 1993; Song, 1980; Sun and Zhao, 2007). Based on the more or less specific worms recorded in the *Jin Si Xuan Xuan* (金笥玄玄) of *Yi Men Guang Du* (夷门广牍), written by Zhou Lüjing (周履靖) during the Ming Dynasty (AD 1368–1644), some of these descriptions, along with those in other medical texts, as well as interpretations made by medical historians can be linked to specific parasites that we know today. Nevertheless, some of those nine worms, such as *fei chong* (肺虫), cannot be reliably associated with any valid modern helminth species (Fig. 3).

Figure 1 shows roundworm distribution as identified archeologically in central and southern China. Finds of roundworms at the Xuanquanzhi archeological site, Gansu Province, confirm the presence of roundworms in ancient northern China. Despite the paucity of data and some gaps in the paleoparasitological record, it appears that roundworms were common in early China throughout the entirety of its life cycles of the three human *Taenia* tapeworms showing distinct scolex and gravid proglottid morphology in adult worms and different organotropism in the larval stage. Adapted from Eom (2006) and Galán-Puchades and Fuentes (2013a,b).
territory. This inference is supported by early medical texts and historical records suggesting that it was not unusual for people to contract parasites at that time. Roundworms appear to have been the most common endoparasite mentioned in the early texts. The presence of blood flukes is better documented in southern China. Indeed, mummies infected with these endoparasites are found mainly in southern China. Eggs identified as those of Taenia sp. were found at the Relay Station site in the northwestern part of China. Consequently, the transmission of Taenia sp. from central or southern China could be ascribed to travelers passing through the relay station. The climate in that region favored the preservation of organic remains, which allows archeologists to recover the eggs.

Apart from the geographical distribution of ancient parasites, social and cultural contexts should be taken into account in any interpretation of these finds as parasitic infections may show a degree of variation among different social classes. In many cases, parasites identified in early China were associated with the remains of individuals that had high social status, such as governmental officials or nobles (Hsiao, 2000; Yeh and Mitchell, 2016). Parasitic disease affects people differentially in accord with the ways in which their food consumption, food production, hygiene practices, and living environments may or may not favor the contraction and spread of parasites. Because social status and cultural practices often affect access to certain foods and modes of food preparation, we expect that levels of parasitic infection to vary between different sociocultural groups. Therefore, when relying exclusively on data obtained from archeological contexts, we are unable to support a hypothesis that parasitic infections preferentially affected people of higher social statuses. Given the scarcity of archeological finds of the eggs of specific parasites, we need to complement paleoparasitological records by examining historical records if we hope to understand the distribution of parasites in the past. Historical records suggest that people of low social status also commonly contracted parasitic infections by consuming certain foods or living in close proximity to environments infested with helminths, such as marshy areas (Chao, [1982]; Zhang, 1995).

Needless to say, poor hygiene practices increased the risk of parasitic infections in the past, as they do in present. Lack of knowledge, lack of public latrines, and poor management of “night soil” likely led to a high prevalence of parasites in early human communities. Historical records from China describe feces littered in public areas. Hou Han Shu (Book of the Later Han), written by Fan Ye (AD 398–445, with no accurate date), recorded that it was common to see feces left along the streets. It is highly likely that these feces contained parasitic eggs (Fan, 1965). The lack of fertilizer for use in agricultural fields was blamed on feces consumption by pigs and dogs during the Southern Song Dynasty (AD 1127–1279) in Yang County, Shaamxi (Chen, 1990). Dogs and pigs would commonly consume feces along the streets, leading to the spread of parasitic diseases, particularly roundworm, which can be passed between pigs and humans (Hsiao, 2000; Leles et al., 2012; Takata, 1951).

Another factor possibly contributing to the increased risk of people contracting parasites was agricultural practices. Human feces were prized by farmers as fertilizer in early China; this practice can be traced back to the Shang Dynasty (c. 2070–1600 BC), and is still common in some parts of China today (Xu, 2005). Moreover, latrine areas that incorporated pigpens ensured that pigs had easy access to human feces (Fig. 4). This practice can be traced to the Warring States era (475–221 BC) (Hsiao, 2000). There has been an abundance of research on A. lumbricoides (human roundworm) and A. suum (pig roundworm), indicating that pigs and humans easily trade their roundworms with each other (e.g., Anderson, 1995; Crewe and Smith, 1971; Takata, 1951). In fact, these two roundworms appear so close genetically close that data suggest that A. lumbricoides and A. suum should be treated as a single species (Leles et al., 2012).

Fish-farming also contributed to the spread of parasites in early China. Fish-farming was often combined with other production activities, including the rearing of sheep and pigs and gardening (Xu, 1979). The feces of pigs, sheep, and humans often contaminated nearby ponds.
and were used as fodder. These practices exposed humans to parasites regardless of their social status.

For the time being, relatively few parasitological investigations have been carried out at archeological sites using sediment samples, leading to a dearth of finds and impeding our comprehensive understanding of parasite distribution in early China. Parasite eggs represent fragile organic entities, which are often destroyed post deposition by high humidity, soil acidity, and/or other climatic factors. The observable geographic distribution of parasites in early China has yet to be reliably delineated based on evidence from archeological sources and the analysis of early medical texts.

5. Conclusions

This paper integrates available evidence on parasites in early China from both medical texts and archeological reports, with a focus on three groups of parasite species: roundworm (Ascaris lumbricoides), Asian schistosoma (Schistosoma japonicum), and tapeworm (Taenia sp.). We show that people in early China faced similar types and degrees of exposure to parasitic infection as do the members of contemporary farming societies in the region. In general, parasitic infections in early China could have been associated with people’s preferences for consuming raw or undercooked animal products, poor hygiene, and specific farming practices. Early physicians noted that consuming raw meat could result in contracting endoparasites. Early Chinese medical practitioners also proposed that certain food combinations could reduce the risk of parasitic infections, such as eating meat with coriander juice or elm sauce (Zhang, [2011]), as well as avoiding the consumption of raw fish with melons or pork livers (Jia, [1985]). However, we are unable to establish, with any degree of certainty, how many of the proposed remedies and recommendations recorded in early medical texts were actually adopted by people at the time. Some of the remedies for parasite infection proposed in the ancient texts, such as consuming meat or fish with coriander juice or elm sauce, are yet to be proven effective at preventing helminth infection or treating parasitosis. Nevertheless, these early medical treatises collectively underscore that physicians long ago were aware of the dangers of consuming raw meat and fish; a well-known route for the transmission of certain parasites.

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