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Paleoparasitology and pathoecology in Russia: Investigations and perspectives

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ABSTRACT

Russia, both as the USSR and the Russian federation, provided a source of parasitological theory for decades. A key figure in Russian parasitology was Yevgeny Pavlovsky. He developed the nidus concept of Pavlovsky provided the conceptual basis for the field of pathoecology. He also coined the term "Paleoparasitology". Pathoecology is a foundation concept in archaeological parasitology. Paleoparasitology, as defined by Pavlovsky, is an avenue for understanding of host parasite evolution over very long time periods. These contributions are not fully recognized internationally. Similarly, the long history of Russian paleontological and archaeological investigations are not fully known. Most recently, discoveries from archaeological sites show that a pattern of zoonotic infection prevailed among archaeological populations in central Russia. This included a case of apparent host switching of beef tapeworm infection to reindeer. This latter discovery raises the possibility that archaeological parasitology can contribute to the new Stockholm Paradigm of ecological fitting, host switching, and emergent disease. This review covers all of the parasitological discoveries from ancient Russia and illustrates how Russian models and discoveries defined parasitological theory in the past and present.

1. Introduction

In recent years, Russian parasitologists in Russia have increasingly focused on archaeological evidence. The approach in Russia, as on other parts of the world, is based on the nidus model of pathoecology. This approach has special importance in Russia. The pathoecological approach is based on the "natural nidality" concept of Y. Pavlovsky, an extremely important Russian parasitologist and epidemiologist. Notably, Pavlovsky introduced the term "paleoparasitology" in 1948 as applied to paleontological discoveries of the era. However, paleopathologists are, in general, ignorant of Pavlovsky's specific contributions and Russian research in general and specifically the derivation of paleoparasitology from his work. We are taking this opportunity to provide a historical background of Russian research.

Based on Pavlovsky's work, pathoecology is an approach developed by archaeological parasitologists to reconstruct the infection modes and localities within and between sites (Martinson et al., 2003; Reinhard and Araujo, 2014; Reinhard and Araujo, 2016). Specifically, Reinhard and Bryant (2008) established nidality as the underlying conceptual structure of pathoecology. Pathoecology is the interaction between parasitism, nutritional adequacy and behaviors such as sanitation and medicinal which define the disease state of a community. Nidality relates to the specific environments in and around the community where infection occurred.

Yevgeny Pavlovsky (1884–1965) was a Russian Soviet parasitologist who introduced the concept of "natural nidality" of parasitic transmission (Pavlovsky, 1966). As a parasitologist and epidemiologist he was recognized in the Soviet Union for his many scientific achievements. Some of his awards were the Stalin State Prize (1941, 1950), the Lenin Prize (1965), the Mechnikov Gold Medal of the Academy of Sciences of the USSR (1949), and gold medal of the Soviet Geographical Society (1954). Outside of the USSR, his seminal work was translated into English by Frederick K. Plous, Jr. and edited by Norman D. Levine. This book was *Natural Nidality of Transmissible Diseases, with Special Reference to the Landscape Epidemiology of Zooanthroponoses*. In this work, he established the idea that microscale transmission foci are determined by entire ecosystems. In his time, his concept established a foundation for infection preventive measures. After his death, the "natural nidality" concept was used in developing landscape parasitology. It was a major influence in epidemiology and parasitology. Pavlovsky established that most transmissible diseases exist in nature as discrete foci or nidi (sing. nidus, "hearth" or "home"). A nidus is

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defined as that portion of a natural geographic landscape which contains a community consisting of a pathogen, vectors, reservoir hosts and recipient hosts, and possessing an environment in which the pathogen can circulate. This concept was incorporated by archaeological parasitologists in the concept of pathoecology. Several authors now incorporate Pavlovsky's concept into the reconstruction of archaeological pathoecology (Dittmar et al., 2012; Reinhard, 2008a; Reinhard, 2008b; Reinhard and Araujo, 2012; Reinhard and Araujo, 2014; Bryant and Reinhard 2012; Reinhard and Bryant, 2008). Reinhard and Bryant (2008) developed the nidus concept in context of archaeological field methods which are designed to uncover microscale features related to specific activities such as food storage, processing, and sanitation. These activities created nidi in the past. These nidi persist as archaeological features to be documented by archaeologists. Using this methodological foundation, Reinhard and Araujo (2014) developed a specific research design that archaeologists are implementing in the field to define nidi of *Trypanosoma cruzi* transmission. It is of significance that the pathoecological approach to ancient parasite transmission had a Russian origin in Y. Pavlovsky. Our review of Russian archaeological parasitology is presented in terms of pathoecology, recognizing the Russian origin of this theoretical approach.

In 2013, the senior author contacted Araújo and Reinhard to begin research collaboration. The resulting partnership resulted in the production of new research. The present article tries to throw light on the main stages of revelation and investigation of parasites in Russian archaeological context in order to reconstruct aspects of life of the ancient population. We also propose to incorporate Pavlovsky's idea's into future work in Russia.

1.1. Paleoparasitology as first defined in Russia

In Russia, the earliest parasitological observations were obtained at the beginning of the 20th century from paleontological contexts. Pavlovsky was aware of past and ongoing research when he composed one of his major works in 1946 Handbook on Parasitology of Man and Theory on Vectors of Transmissible Diseases" (Pavlovsky, 1946). In that books (in Russian version 1946), he introduced "paleparasitology" as a field that had potential in contribution to understanding of host-parasite interaction and evolution. His prediction has only recently come to fruition, especially with the advent of modern systematics and phylogenetics (Hugot et al., 2014), and in context with the maturation of molecular biology (Leles et al., 2012). In this article we have given information about 15 paleontological and archaeological sites in Russia, where the parasites were found (Fig. 1; Table 1).

1.2. Paleoparasitological discoveries

First, in 1909, Vladimir Zalevskiy and Fadey Byalynitskiy-Biruley published detailed results of their study of the Berezovsky mammoth remains. The Berezovsky mammoth was an almost perfectly preserved mammoth found in 1901 on Berezovka River (right tributary of Kolyma River). The published study included description of mammoth anatomy as well as histology of its bones and soft tissues (Balyanitskiy-Birulya, 1909; Zalenskiy, 1909). Both authors reported pathological changes in mammoth' stomach, including multiple hemorrhages (hematomas?) in submucosa and muscle layers. They describe: "accumulations of problematic entities in submucosa (muscularis serosae) of mammoth' stomach" [«скопления проблематических тел в подслизистой ткани (muscularis serosae) желудка мамонта».] The authors did not provide any explanation for the observed abnormalities. However, research of the Magadan mammoth, carried out by E. Ivanova 70 years later, inferred that the Berezovsky mammoth had a parasitic infection of some sort.

The Magadan baby mammoth was discovered in Magadan region in 1977, near the town of Susuman. E. Ivanova studied a range of tissues from that mammoth. Her histological analysis of blood vessels and blood from the vena cava caudalis discovered round plaques ranging in size from 0.01 to 0.06 mm, which E. Ivanova interpreted as helminth eggs. Furthermore, she discovered fragments of parasitic worms that measured 0.1×0.05 mm as well as multiple cavities surrounding blood vessels, where parasites matured during the initial phases of infection. Walls of vessels and surrounding tissues that were infected with parasites contained multiple hemorrhages (hematomas) and islands of necrotic tissue. In addition, E.I. Ivanova reported that the lobes of the thyroid gland were filled up with helminth eggs (Ivanova, 1981).

Comparing the "problematic entities" that were described and sketched by V. Zalevskiy and F. Byalynitskiy-Biruley in the stomach area of Berezovsky mammoth with the eggs and cysts found during the study of Magadan mammoth, E. Ivanova observed that these are identical. She also proposed that observed pathologies are consistent with chronic or acute cysticercosis of herbivorous and omnivorous mammals. For instance, similar histological changes are typical for acute cysticercosis in reindeer (Mitskevich, 1962; Ivanova, 1981).

A body of young male mammoth of species *Mammuthus primigenius*, (Blumenbach, 1799) was discovered in 2012, not far from Sopochnaya Karga station, hence dubbed Sopochnaya Karga mammoth. Soft tissues on the right side of the body were partially preserved. The mammoth body also retained fragments of heart, liver, and the contents of large intestine. Fragments of muscle, liver, and contents of rectum where examined parasitic infection. Eggs of multiple helminths, including those of Plathelminthes and Nemathelminthes types of Cestoda and Nematoda classes respectively were found (Glamazdin et al., 2014).

In January 1968, mummified remains of an ancient horse were found at a gold mine in Selerikan in the Balkhan brook valley (the upper reaches of the Indigirka River), at a depth of 8–9 m in the permafrost. The remains have an absolute dating of 37,000 years (radiocarbon dating of the plant remains from the stomach) (Arslanov and Chernov, 1977). During analysis of the intestinal contents the researchers found in the colon a few nematodes of the suborder *Strongylata* and a shell of a mite of the suborder *Oribatea*. Analysis revealed 4 entire males, 2 males without anterior sections, 6 separated anterior sections and 2 fragments of midsection. Entire females were not present. The analysis of the material showed nematodes belong to *Alfortia edentatus* (Dubinina, 1972).

The next paleoparasitological works were published after World War II in the USSR and all of them have been carried out on the material of Pleistocene animals. V. Dubinin studied mummified gophers from the Indigirka River, of absolute dating of 10,000 to 12,000 years. The guts of mummified rodents contained the nematode *Syphacia* sp. (Oxyuroidea**)** (Dubinin, 1948).

While analyzing mummified bison, dated about 37,000 years before present, Shakhmatova found nematode genus *Skrjabinagia Kassimov, 1942 (*Nematoda, Trichostrongylidae) (Shakhmatova, 1988).

Savinetsky and Khrustalev also performed helminthological analysis of excrement samples collected from Pleistocene deposits of Siberian goat droppings. They were found in Yaroldzyhtynsky cave in southern Mongolia dating 33,653 ± 1638 years ago. The samples revealed eggs of the helminth genus *Nematodirus*. The researchers continued their investigations of ancient parasites in 1992 and published another article revealing the results of the analyses of dung deposits from the caves and places of animals breeding. They analyzed 77 samples from five locations in North Ossetia, Turkmenistan and Mongolia. However, the authors simply listed the presence of the helminth genera *Fasciola* sp.*, Dicrocoelium* sp.*, Trichuris* sp.,. *Capillaria* sp.*, Dicrocoelium* sp.*, Nematodirus* sp.*,* and *Oxyurida* without discussion or interpretation of the results. In conclusion the authors wrote how advanced a paleoparasitological analysis is for studying the history of the worm prevalence, speciation, the formation of helminth infections, migration routes and identification of domesticated animals, and for paleoecological studies (Knyazev and Savinetsky, 1992).