



OPINION ARTICLE

REVISED Pathogenic helminths in the past: Much ado about nothing [version 3; referees: 2 approved]

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Abstract

Despite a long tradition on the extent to which Romanisation has improved human health, some recent studies suggest that Romanisation in general, and Roman sanitation in particular, may not have made people any healthier, given that in Roman times gastrointestinal parasites were apparently widespread, whilst in the present day such parasites rarely cause diseases. Unfortunately, this novel claim neglects the empirical evidence that worldwide infections in over 1.5 billion people are caused by ubiquitous foodborne nematodes. Therefore, many may wonder if fossil remains of soil-transmitted helminths have been reported in ancient sanitation infrastructures. Beneficial access to improved sanitation should always be prioritized, hence how can historical sanitation efforts have ever been harmful? In this short article, a strong plea for caution is given, asking for an augmented nematological record and showing that there is not any evidence against Roman sanitation, neither in the past nor in the present.

Open Peer Review

Referee Status:

	Invited Referees	
	1	2
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- 1 **Karl J. Reinhard**, University of Nebraska, USA
- 2 **Cornelis van Tilburg**, Leiden University, Netherlands

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Author roles: Mulder C: Conceptualization, Writing – Original Draft Preparation, Writing – Review & Editing

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REVISED Amendments from Version 2

There are apparently different views on Roman water technology, hence I improved my take-home message on public health. The suggested attempt to explain the historical occurrence of helminth eggs in urban areas by a possible increase of manure application in the countryside is challenging although out of the scope of this communication, but for those interested in that aspect I strongly recommend literature reviews like Dark & Gent in Oxford Journal of Archaeology 20(2001):59–78 doi/10.1111/1468-0092.00123

See referee reports

In her *Nature* feature, Chelsea Wald¹ reviewed some of the conclusions by Piers D. Mitchell² and describes the fascinating rise of latrines in Mesopotamia, Greece and the Roman Empire. Both authors tried to point out that most of these sanitation facilities were not doing much for the residents' health, despite the idea that sophisticated plumbing systems, like those of ancient Rome, may have acted as a kind of control that could benefit even the poor. This debated interpretation was based on the fact that human hosts mainly acquire infective nematodes via the faecal–oral route through the soil, although unembryonated eggs can remain viable in the soil for 15 years. Helminth preservation seems to be the highest in moist anaerobic environments like latrines³; therefore, even

Roman latrines, with continuous flushing and related sediments (coprolites), can become valuable for the reconstruction of past gastrointestinal infections, if evaluated correctly.

As a matter of fact, water purification will always be one of the most intriguing examples of how public health and societal health are interwoven. Amazing examples come from Roman history, where water and wastewater systems rapidly became pillars for European civilisation. The large-scale introduction by Romans of fountains into or near public buildings, together with closed aqueducts, can be seen as the very first Water Safety Plan. Interestingly, archaeologists somehow seem to be ideologically motivated to conceptualize diseases and outbreaks in Roman times, despite the thin palynological record from ancient sanitation infrastructures around the Mediterranean Sea^{1,2} (Figure 1).

Many pathogens are reported in ancient latrines because they are intrinsically correlated to human settlements, and not to sanitation infrastructures themselves, which are supposed to reduce the risk of contact with outbreak sources. On one hand, it is true that fossil remains of roundworms, whipworms and hookworms (collectively referred to as soil-transmitted helminths) have been reported from ancient sanitation infrastructures. On the other hand, Romans were fully aware of the importance of clean water and efficient sanitation systems. Already during the short reign of

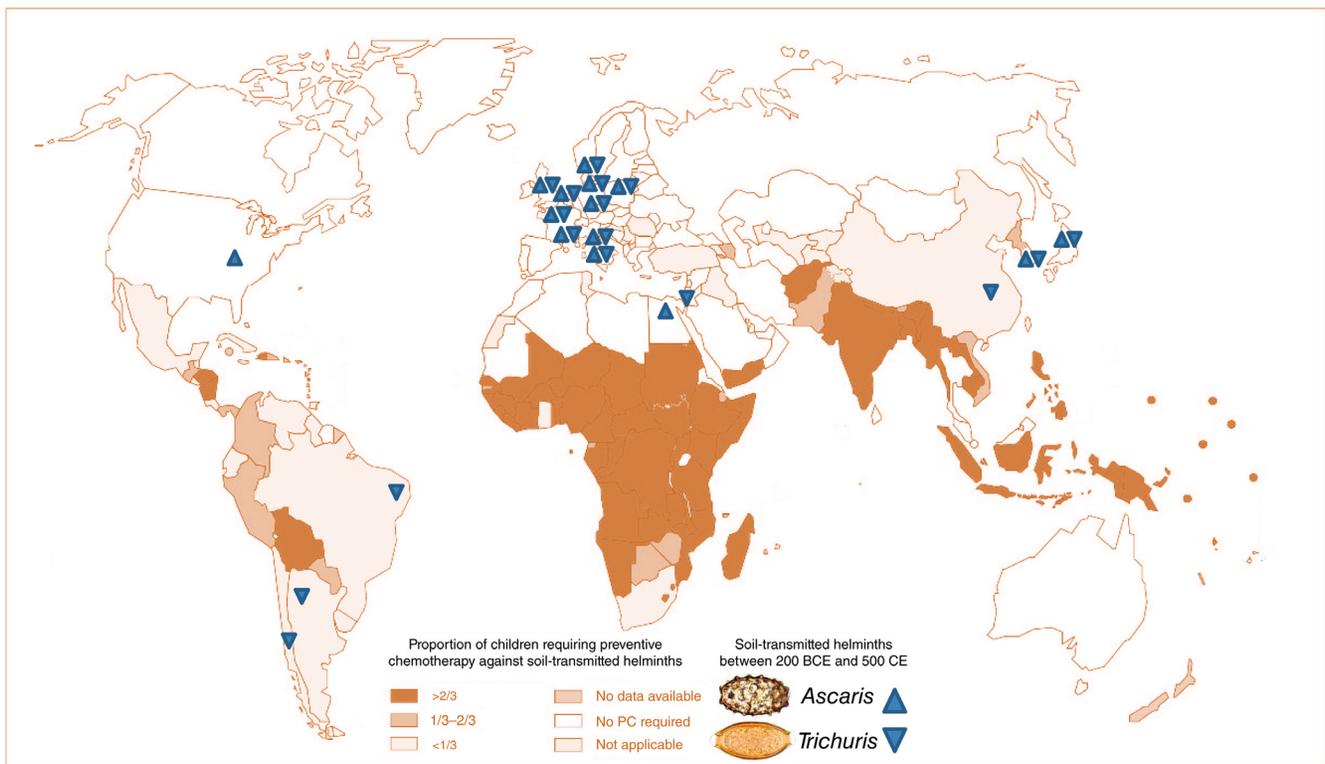


Figure 1. Multiple geographical and historical investigation bias between ancient settlements claimed to be infected in the past, and children's helminthiases in modern countries. Background map implemented with palaeoparasitological records of roundworms (*Ascaris*) and whipworms (*Trichuris*) recovered from a global selection of archaeological sites built between 200 BCE and 500 CE (Common Era)^{2,4-8}. The background map has been adapted from World Health Organization, program on Control of Neglected Tropical Diseases (gamapserver.who.int/mapLibrary/Files/Maps/STH_2011_global.png).

Nerva in Rome (96 – 98 CE), Frontinus decided that water from different sources had to be kept separate: clean water was reserved for potable use, intermediate quality water was used for recreation and only poor quality water was sent for irrigation. Thanks to sophisticated hydraulic systems for aqueducts, cisterns, pipes, therms, baths, fountains and latrines, the capital of the Roman Empire became famous as *Roma regina aquarum*. Due to the greatest care provided to their waters for the health and security of the capital and later of the other cities, these neglected latrines became an open archaeological window not so much on Roman sanitation, but on our civilisation as a whole. Fossilized helminth eggs in dung sediments from latrines are very peculiar tools to reconstruct migration routes, trades, animal domestication, diets, past outbreaks and even urban catastrophes⁴⁻⁶.

Nematodes are the most frequently occurring invertebrates. These primitive soil organisms occupy diverse trophic levels in ecological networks and can act either as antagonists for soil-borne pests or be pathogens themselves. It can be dangerous to suggest that sanitation may not have made people any healthier, as humans can also get infected with soil nematodes by ingesting unclean vegetables or by contact with infected domestic animals. Along the aforementioned faecal–oral route, behavioral and allometric factors have been put forward in existing literature⁹, being the host-related factors linked to human size prominent. According to host–parasite regression models for mammals⁹ and assuming on average one adult body weight of 62.0 kg (corresponding to a volume of 61,400 cc), each infected human might contain up to 12,300 helminths.

Hence, it is not surprising to find helminths in sanitation systems of ancient settlements, especially if only the palaeoparasitological data for sites at which these pathogens were detected are gathered together. For instance, archaeological records of common-source outbreaks can be collated to support the idea that sanitation facilities historically linked to Romanisation have widespread helminths, although these cosmopolitan endoparasites are well-known to occur during Roman times even around the Pacific Ocean, including the New World in pre-colonial times^{5,7,8,10} (Figure 1). Thus, we have to realize that there would be many more helminth eggs in ancient sanitation facilities if these facilities had not been there in the past. Surprisingly, archaeologists like to invert this basic framework, and suggestive interpretation may be worse than no interpretation at all.

But even if such pathogens are identified, it remains challenging either to exclude false parasitism (incidental presence in human faeces of eggs resulting from the consumption of an infected animal^{7,11}) or to determine with certainty human outbreaks (helminth eggs might demonstrate their human origin by some circumstantial evidence only^{3,11}). Allometric rules that express parasites and non-infected animals per square meter¹², in tandem with the several

possible contamination pathways, will always lead to diseases with a high global burden¹³. Moreover, a parasitic occurrence can also be related to open water contamination, for instance from livestock grazing in upland areas causing outbreaks downstreams. This has nothing to do with any sanitation structure, as these parasites are by far common and overdispersed¹⁴⁻¹⁶: hot spots examples of faecal contamination, as shown by highly aggregated *Ascaris* or *Trichuris* eggs, are in fact well-known in archaeology and palaeoecology^{11,17,18}.

Omitting such a relevant weight of evidence in any comparison between archaeological excavations will introduce *de facto* a strong bias towards false-positive results into palaeoecological meta-analyses. In the future, to avoid interesting, but geographically misleading or even statistically speculative conclusions, one of the most intriguing hypotheses that will arise might be the investigation by microscopy of soils from archaeological sites associated either with one sanitation infrastructure or without that sanitation. In the case of Roman sanitation, due to the Hadrian's Wall bordering the northern part of the Roman Empire with all its social infrastructures, including latrines, England (entirely inside the Wall during Roman times) and Scotland (outside the Wall during Roman times) can together provide the perfect study area. Again, it seems necessary to emphasize that the Romans created an original system of public sanitation and water distribution on a scale not seen before simply because they linked as first individual hygiene to public health. As it is all too easy to spot patterns in randomly collected data, objective empirical evidence that correlations are real demands a well-designed survey to avoid any suspicion.

There are 2.5 billion people still living on Earth without improved sanitation facilities and an ensured availability of sanitation worldwide is one of the core United Nations targets to end poverty in 2030 (<http://www.un.org/sustainabledevelopment/sustainable-development-goals>). Therefore a correct data mining of all nematological records¹⁹ combined with objective interpretation of, probably thin, circumstantial evidence will require great care, as the conclusion shall have implications on ongoing global control programs relating to helminthiases. On the other hand, as the taxonomic status of *Ascaris* is contentious²⁰, palaeoecological evidence from archaeological sites in synergy with present-day molecular ecology can become an unexplored avenue to improve current control programs.

Competing interests

No competing interests were disclosed.

Grant information

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Open Peer Review

Current Referee Status:  

Version 3

Referee Report 22 August 2017

doi:10.5256/f1000research.13422.r24946



Cornelis van Tilburg

Centre for the Arts in Society, Leiden University, Leiden, Netherlands

After his revisions, I agree with the revised article of Christian Mulder.

Competing Interests: No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 2

Referee Report 08 August 2017

doi:10.5256/f1000research.13196.r24554



Cornelis van Tilburg

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In Mulder's article "Pathogenic helminths in the past: Much ado about nothing", Chelsea Wald and Piers D. Mitchell state that sanitation did not improve people's health significantly, despite its sophisticated technique. In coprolites and remains of toilets throughout the Roman Empire the presence of helminth's eggs of *Ascaris* and *Trichuris* was widespread, testifying to the unhealthiness of the environment.

Mulder states that helminths arrive in the faeces deposit (dung heap or sewer system) through the oral-faecal route; people are infected by eating infected food and drinking infected water, so that there is no immediate connection between sanitation and 'eating' helminth's eggs. Mitchell correctly observes that a concentration of faeces is a breeding-place for parasites and eggs. Faeces was used as a fertilizer in the countryside, so that helminth's eggs were spread.

Comparing ancient sanitation with modern sanitation is not without risk. Mulder's statement 'The large-scale introduction by Romans of fountains into or near public buildings, together with closed aqueducts, can be seen as the very first Water Safety Plan' (second paragraph, 'As a matter ... Sea') is disputable. The aqueducts were closed, indeed, but this construction served to prevent pollution (e.g. by pieces of wood) or even poisoning¹. Moreover, ancient 'safe water' differs from modern 'safe water'².

Nowadays, 'safe water' is water without pollution of by parasites, chemicals, etc. In Antiquity, 'safe water' was clear, without smell or taste, like rain and spring water. On the other hand, the aim of the authorities was the same: to improve health and sanitation as much as possible by supplying 'safe water', but the awareness of the Romans was restricted. If necessary, surface water was filtered³, but they were unable to remove invisible but noxious elements like helminths' eggs.

In the third paragraph ('Many pathogens ... catastrophs') Mulder refers to a tripartite division of waters ('Already... irrigation'), which would be mentioned by Frontinus. I am not aware of any mention of a tripartite division of good, intermediate and bad water in Frontinus; a reference would be welcome. In ch. 11 of *De aquis*, Frontinus describes how the Aqua Alsietina, supplying water of less quality, was constructed for the Naumachia, a pond for reenacting sea-battles; this aqueduct was not connected with the other aqueducts, being situated on the right bank of the Tiber river. This water was not used, in the first instance, for consumption; surplus of the Naumachia was used for the irrigation of private gardens⁴. In the chapters 88-93, Frontinus criticizes the indiscriminate use of water from aqueducts for any purpose (for instance, the use of clear drinking water for fulleries), and pleads for separating all aqueducts; some aqueducts (like Marcia) containing excellent water have to supply drinking water, other ones (like Anio Vetus) for other purposes⁵.

A small correction in this paragraph: for 'terms' read 'thermae' – which, however, is already covered by 'baths'. I advise to delete this word.

Conclusion: Mulder discusses the influence of sanitation on hygiene and health in Antiquity. He disagrees with Mitchell, who states that the improvement of sanitation did not improve human health very much. Bodily hygiene increased by the use of bathhouses, but the number of helminths did not diminish due to the growing use of faeces as fertilizer. Mulder rightly argues that one should not too readily conclude that the development of sanitation did not contribute to the health of the population significantly; more research comparing areas both within and outside the Roman Empire is certainly required. Please add references of Frontinus.

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Is the topic of the opinion article discussed accurately in the context of the current literature?

Yes

Are all factual statements correct and adequately supported by citations?

Partly

Are arguments sufficiently supported by evidence from the published literature?

Partly

Are the conclusions drawn balanced and justified on the basis of the presented arguments?

Partly

Competing Interests: No competing interests were disclosed.

Referee Expertise: Traffic and medicine in the Graeco-Roman Antiquity

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 08 Aug 2017

Christian Mulder, RIVM, Netherlands

I am grateful for the comments by van Tilburg, with whom I agree that present-day microbiological criteria are inapplicable to ancient sanitation systems. However, it seems to me also relevant to state that by changing the (Hellenistic) cisterns – open streaming water cyclus into a distribution system based on streaming and flushing in pipes, the Romans provided globally the very first improvement in human health and public sanitation. Even Plinius [as mentioned by van Tilburg (2013) in the *Eå Journal*] reported that cistern water had to be regarded as unhealthy, clarifying the relevance of streaming waters. On the other hand, there was surely a huge difference in the water quality across the Roman Empire, with some severe historical cases of poisoning and heavy metal pollution around the borders. But the few citations by van Tilburg are neither examples of human contamination by intestinal parasites nor examples of incorrect water distribution [please read a.o. P. Pace (1983) *Gli Acquedotti di Roma*, pp. 330, and Rodgers' English translation of Frontinus' *De Aquaeductu Urbis Romae, Liber Alter*]. As a matter of fact, there has not been during the past a significant growing use of human faeces as fertilizer, but simply an increase of manure application as shown in hundreds of palynological records by the kind of coprophilous dung fungi recorded across Europe and in some sites of Africa. Hence, also the suggested growing use of manure did not occur in urban ecosystems (and van Tilburg correctly wrote "Faeces was used as a fertilizer in the countryside"), although in some countries this unfortunate coexistence of cattle, dogs and people remains an everyday reality. In any case, access to piped water is considered central for a prevention of soil-transmitted nematodes. This reinforces my plea for a better comparison of areas within and outside the Roman Empire and I am very happy to see that also van Tilburg sees it as required. Such pathogens are in fact known from proto- and prehistoric Europe in the Neolithic and during the La Tène culture, and after the decline of the Roman Empire in the post-medieval period as well. Hence, the mechanistic factor beyond the occurrence of helminth eggs is not the Roman water infrastructure (as suggested by archaeologists like P.D. Mitchell), but something else that has still to be discovered (Scarce vegetation cover? Poor-quality housing? Domestic behavior?). Summarizing, these pathogenic nematodes have been widely reported in archaeobotanical and palynological literature because they are intrinsically correlated to human settlements, and not to sanitation infrastructures which only reduce the risk to get in contact with such outbreak sources.

Competing Interests: No competing interests were disclosed.

Referee Report 17 July 2017

doi:10.5256/f1000research.12694.r23627



Karl J. Reinhard

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Christian Mulder's "Pathogenic helminths in the past: Much ado about nothing" reveals some basic problems with the research presented by Piers Mitchell in "Human parasites in the Roman World: health consequences of conquering an empire. Parasitology". The critique recognizes that the conclusions of the study are overblown and points to errors in methods and theory. I read Mitchell's work and concur with Mulder. Mitchell does not approach the problem from the perspective of the science of archaeology nor the science of parasitology. Mulder suggests that Mitchell did not control for false parasitism through spread of eggs through the environment. In the science of archaeology, as applied to parasitology, concentrations of parasite eggs per ml or gr are calculated by researchers. These calculations document the distribution of eggs through strata within pits and across ancient village landscapes. This leads to statistical identification of transmission points. When these archaeological egg accumulations are verified as fecal deposits via ancillary pollen and seed analysis, then fecal contamination "hot spots" are defined. Dating of these points can lead to very solid information about emergence and control of geohelminths. This has been demonstrated archaeologically by the references of Fisher and Trigg's work below. Secondly, the geohelminth life cycle of ascarids seems to be misunderstood by Mitchell who asserted that people could have been infected in Roman baths.

I have a paper that has just been published addressing rigor in archaeological parasitology. This highlights the sort of issues such as false parasitism noted by Mulder.

I believe that Mulder is spot on with regard to Mitchell's assertion. I strongly recommend this work for indexing and I would hope that Mulder includes references to the work by Fisher's team and Trigg's team. The work by Trigg is in press and can be obtained via Heather Trigg or Steve Mrozowski.

Useful References:

- Fisher et al. (2007)¹
- Trigg et al. (2017)²
- Reinhard (2017)³

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Is the topic of the opinion article discussed accurately in the context of the current literature?

Yes

Are all factual statements correct and adequately supported by citations?

Partly

Are arguments sufficiently supported by evidence from the published literature?

Yes

Are the conclusions drawn balanced and justified on the basis of the presented arguments?

Yes

Competing Interests: No competing interests were disclosed.

Referee Expertise: Archaeoparasitology, palynology, paleoparasitology, paleonutrition, archaeobotany, palynology

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.
