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MINIREVIEW

Medical Parasitology Taxonomy Update, 2016–2017

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ABSTRACT Parasite taxonomy continues to change as molecular and morphologic studies enhance our understanding of parasite relatedness. This minireview builds on the information provided in the last taxonomy update in this journal to summarize new and revised clinically relevant human parasite taxonomic changes that have occurred in 2016 and 2017.

KEYWORDS taxonomy, parasitology, parasite, worm, helminth, protozoa

Parasites encompass a diverse number of protozoan and metazoan (helminthic and arthropod) parasites. Taxonomy is an ever-changing field of biology, and as we better understand the relationships between various organisms, taxa are downgraded, upgraded, shifted, and described accordingly. While morphologic features were traditionally used to describe and classify the various parasites, and still are with most metazoan parasites, molecular studies conducted over the past several decades have redefined our understanding of parasite relatedness and now form the basis for our current hierarchal classification system. As such, the current classification system reflects our prevailing understanding of how parasite clades—monophyletic lineages that are thought to have evolved from a common ancestor—are related to one another. This system is described in detail by Adl and Mathison in the 12th edition of the *Manual of Clinical Microbiology* (in press) and represents the taxonomic scheme used by biologists and researchers for more than a decade (1). The biggest change to the new classification system is the reduced emphasis on named ranks of complexity such as class, order, and family, given their somewhat artificial and occasionally misleading nature, especially with regard to protozoan taxonomy. Metazoan parasites (helminths and arthropods) continue to follow the classic Linnean hierarchal system. Regardless, most organisms categorized as "parasites" in the medical and public health realm are still governed by the International Code of Zoological Nomenclature (ICZN) when it comes to species descriptions and designations.

This minireview builds upon the last parasite taxonomy update published in this journal (2) to summarize new and revised clinically relevant parasite taxonomic changes that have occurred in 2016 and 2017. Also included are clinically relevant taxonomic changes that have occurred in the past decade and which were not included in the last update.

METHODS

A systematic review was conducted using several reference materials to identify peer-reviewed studies describing parasite taxonomic changes of clinical importance published during January 2016 through December 2017. Among the sources consulted were the *Manual of Clinical Microbiology*, 12th edition, section VIII: Parasitology (in press), and the U.S. Centers for Disease Control and Prevention's Division of Parasitic Diseases and Malaria (DPDM) DPDx website (https://www.cdc.gov/dpdx/). A systematic literature search of the PubMed database (U.S. National Library of Medicine National Institutes of Health; https://www.ncbi.nlm.nih.gov/pubmed) was also performed using

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the keyword search phrase "nov. sp." to identify newly described taxa. Only parasites detected in human specimens were included.

RESULTS

Revised and new parasite taxa reported from January 2016 through December 2017 are listed in Tables 1 and 2, respectively, along with their clinical relevance. Defining laboratory characteristics are also provided for new taxa. During the literature review, several clinically relevant taxonomic changes, additions, and insights that had been described since 2012 but not included in the prior edition of this review were also noted and were therefore included in this minireview.

DISCUSSION

Revised taxa. Clinically relevant taxonomic revisions have occurred for both protozoa and helminths. While the change to the genus name *Balantidium* (now *Neobalantidium*) impacts just a single human-pathogenic species, recategorization within the genus *Diphyllobothrium* has impacted multiple species, including the prototypical *Diphyllobothrium latum* (now *Dibothriocephalus latus*). These changes are described in further detail below. New insight regarding *Blastocystis* and *Macracanthorhynchus* also have important implications for diagnosis and reporting in the clinical microbiology laboratory and are thus discussed below.

***Neobalantidium*.** *Balantidium coli* is a cosmopolitan parasite inhabiting the intestinal tract of mammals, including humans, in whom it causes the clinical disease balantidiasis. Recent molecular studies have demonstrated that *B. coli* does not appear to be congeneric with the type species in the genus, *Balantidium entozoon* (a parasite of frogs), and the genus *Neobalantidium* was described to accommodate *B. coli* and other *Balantidium* species with warm-blooded hosts (3). As such, the clinical disease in humans should also now be referred to as neobalantidiasis.

***Diphyllobothrium*.** The pseudophyllidean cestode genus *Diphyllobothrium*, which is the causal agent of human diphyllobothriasis, has undergone significant taxonomic changes in recent years, and most of the species associated with human disease have been transferred to the genera *Adenocephalus* and *Dibothriocephalus*, based on both morphological and molecular data. Hernández-Orts and colleagues (4) resurrected *Adenocephalus* to accommodate *Diphyllobothrium pacificum,* and Waeschenbach and colleagues (5) later resurrected *Dibothriocephalus* to accommodate freshwater and brackish species of *Diphyllobothrium*, including *Diphyllobothrium latum*, *Diphyllobothrium nihonkaiense*, *Diphyllobothrium dendriticum*, *Diphyllobothrium dalliae*, and *Diphyllobothrium ursi*, which have all been implicated in human disease. The genus *Diphyllobothrium*, as presently delineated, consists primarily of cetacean (whale) parasites, including *Diphyllobothrium stemmacephalum* and *Diphyllobothrium balaenopterae*, which have been associated with human disease. Two additional species that are tentatively retained in *Diphyllobothrium* include *Diphyllobothrium lanceolatum* and *Diphyllobothrium cordatum* (5).

The taxonomic changes to *Diphyllobothrium* can present reporting issues in the clinical laboratory. The eggs of these genera cannot be reliably separated morphologically, and most clinical diagnostic and reference laboratories do not have the expertise to recognize the genera based on the characteristics of the adults or their proglottids (which is compounded by the fact some of the defining morphologic features are on the scolex, which is rarely recovered in clinical specimens). Historically, laboratories have reported isolates as either *Diphyllobothrium latum* or *Diphyllobothrium* species; however, in the light of recent taxonomic changes, it might be prudent to report all morphologically consistent parasites as "*Diphyllobothrium*/*Dibothriocephalus*/*Adenocephalus*" if advanced morphological or molecular analysis is not available. The disease may still be referred to as diphyllobothriasis, unless the specific genus is known. Regardless of the final report, it is helpful to note that the change in nomenclature does not have any clinical implications.

TABLE 1 Changes in parasite taxa from January 2016 through December 2017[a]

Category	Current scientific name	Previous scientific name	Clinical disease	Rationale for taxonomic change	Reporting suggestion	Reference
Tissue protozoa	*Neobalantidium coli*	*Balantidium coli*	Neobalantidiasis (=balantidiasis)	Based on comparative molecular study with type species of *Balantidium*	*Neobalantidium* (formerly *Balantidium*) *coli*	3
Intestinal cestodes	*Adenocephalus pacificus*	*Diphyllobothrium pacificum*	Adenocephaliasis[b]	Based on comprehensive molecular and morphologic analysis	*Diphyllobothrium/Dibothriocephalus/Adenocephalus*[c]	4
	Dibothriocephalus latus	*Diphyllobothrium latum*	Dibothriocephaliasis[b]	Based on comprehensive molecular and morphologic analysis	*Diphyllobothrium/Dibothriocephalus/Adenocephalus*[c]	5
	Dibothriocephalus nihonkaiensis	*Diphyllobothrium nihonkaiense*	Dibothriocephaliasis[b]	Based on comprehensive molecular and morphologic analysis	*Diphyllobothrium/Dibothriocephalus/Adenocephalus*[c]	5
	Dibothriocephalus dendriticus	*Diphyllobothrium dendriticum*	Dibothriocephaliasis[b]	Based on comprehensive molecular and morphologic analysis	*Diphyllobothrium/Dibothriocephalus/Adenocephalus*[c]	5
	Dibothriocephalus dalliae	*Diphyllobothrium dalliae*	Dibothriocephaliasis[b]	Based on comprehensive molecular and morphologic analysis	*Diphyllobothrium/Dibothriocephalus/Adenocephalus*[c]	5
	Dibothriocephalus ursi	*Diphyllobothrium ursi*	Dibothriocephaliasis[b]	Based on comprehensive molecular and morphologic analysis	*Diphyllobothrium/Dibothriocephalus/Adenocephalus*[c]	5
	Diphyllobothrium balaenopterae	*Diplogonoporus balaenopterae*	Diphyllobothriasis[b]	Based on comprehensive molecular and morphologic analysis	*Diphyllobothrium/Dibothriocephalus/Adenocephalus*[c]	5

[a]Also included in this table are clinically important revisions that were not addressed in Simner (2).
[b]The term "diphyllobothriasis" may be used when the specific genus is not known.
[c]We suggest reporting as "*Diphyllobothrium*/*Dibothriocephalus*/*Adenocephalus*" for morphologically consistent parasites when advanced morphological or molecular analysis is not available.

TABLE 2 Parasite taxa newly described or reported from humans from January 2016 through December 2017[a]

Category	Scientific name	Source(s)	Defining laboratory characteristics	Clinical relevance	Reference
Tissue protozoa	"*Tetratrichomonas empyemagena*"	Pleural fluid, oral cavity	Sequence analysis of the internal transcribed spacer 1 (ITS1)-5.8S rRNA-ITS2 region	Detected in pleural empyema fluid in conjunction with bacteria; clinical relevance not well understood.	11
Tissue nematodes	*Thelazia gulosa*	Conjunctiva	Morphologic features of the female reproductive tract and the form of the buccal cavity	Thelaziasis, zoonotic ocular nematode infection associated with conjunctivitis, foreign body sensation, and excessive lacrimation	10
	"*Dirofilaria hongkongensis*"	Cervical lymph nodes, abdominal and subconjunctival subcutaneous masses	Sequence analysis of *cox1* gene and the 18S-ITS1-5.8S gene	Subcutaneous dirofilariasis (tender, erythematous nodule) and cervical lymphadenopathy	13

[a]Also included in this table are clinically important revisions that were not addressed in Simner (2).

***Blastocystis*.** Blastocystosis is caused by enigmatic protozoan parasites in the genus *Blastocystis*. Historically the parasite has been allied with yeasts, amebae, and coccidians, but it is now believed to be a stramenopile in the stramenopiles-alveolates-Rhizaria (commonly referred to as "SAR") supergroup (1). Traditionally, species have been described based on host data (*Blastocystis hominis* from humans, *Blastocystis ratti* from rats, etc.), and historically, all isolates of humans were referred to as *B. hominis* (6). However, molecular analyses appear to demonstrate that there is no population unique to humans and that all human isolates have animal reservoirs (6, 7). Nine (possibly ten) primary subtypes (genotypes) have been found in mammals and birds, with subtypes 1 and 3 making up most of the cases of human blastocystosis (6). Laboratories that identify *Blastocystis* should be attuned to potential changes in taxonomy as data evolves, and until the taxonomy is resolved, consider reporting this parasite at only the genus level (i.e., "*Blastocystis* species").

***Macracanthorhynchus*.** Most cases of human acanthocephaliasis involve intestinal infection and have been attributed to either *Macracanthorhynchus hirudinaceous* or *Moniliformis moniliformis*. Mathison and colleagues (8) reported the third human case of acanthocephaliasis attributed to *Macracanthorhynchus ingens* and suggested that human infection with *Macracanthorhynchus* in the United States might more likely be attributed to *M. ingens* rather than to the historic *M. hirudinaceous*, especially where its natural definitive host (raccoons) is a common anthropophilic species. The eggs of *Macracanthorhynchus* species cannot be separated morphologically; however, the adults of *M. hirudinaceous* and *M. ingens* can be separated based on a morphometric analysis of the proboscis and its hooks on the proboscis (9). Regardless, it might be prudent to report North American cases attributed to *Macracanthorhynchus* at the genus level unless expertise exists in the laboratory to differentiate the two species. Of note, separation of the two species is not required for clinical management of the patient.

New taxa. In addition to changes to existing taxa, the following new taxa of potential clinical importance have been recently described or isolated from clinical human specimens.

***Thelazia gulosa*.** Thelaziasis is an uncommon zoonotic disease caused by spiruoid nematodes in the genus *Thelazia* (1). *Thelazia* species cause ocular infections in their definitive hosts (primarily cattle, sheep, deer, and other ruminants), and common clinical manifestations in humans include conjunctivitis, foreign body sensation, and excessive lacrimation (https://www.cdc.gov/dpdx/). Historically, human disease was attributed to *Thelazia callipaeda* (Old World) or *Thelazia californiensis* (western North America). Bradbury and colleagues (10) reported the first case of human thelaziasis caused by *Thelazia gulosa* from a patient in Oregon. *Thelazia gulosa* is a common parasite of cattle in North America, Europe, Central Asia, and Australia and is transmitted by flies in the genus *Musca*.

"Tetratrichomonas empyemagena." *Tetratrichomonas* is a trichomonad parasite that commonly infects reptiles, birds, and livestock (11). Like the commensal parasite *Trichomonas tenax*, tetratrichomonads have been previously identified in the oral cavity

and respiratory tract of humans and have been seen in association with pleural empyema, pneumocystis pneumonia, and acute respiratory distress syndrome (12). While previously analyzed parasites have closely clustered with the avian parasite *Tetratrichomonas gallinarum* based on small subunit ribosomal DNA sequence analysis, two groups reported a previously unrecognized *Tetratrichomonas* species in pleural empyema fluid aspirated from three patients (11, 12). Lopez-Escamilla and colleagues proposed that the new species be named *Tetratrichomonas empyemagena* to denote its association with empyema. However, they did not formally describe the name under the guidelines of the ICZN, and thus the name is not currently considered a valid taxon. *Tetratrichomonas* species are microaerophilic organisms and are thus unlikely to cause disease in the absence of predisposing conditions, such as tissue hypoxia, diffuse alveolar damage, and fungal infection (12). Notably, bacteria are routinely isolated from empyema fluid containing *Tetratrichomonas* species and are hypothesized to serve as a food source for the trichomonads.

"*Dirofilaria hongkongensis*." In 2012, To and colleagues identified a possible new *Dirofilaria* species ("*Candidatus* Dirofilaria hongkongensis") in humans and dogs in China, using sequence analysis of the *cox1* and 18S-ITS1-5.8S gene sequences (13). While a formal description does not yet exist for this proposed species, additional genetic studies of complete mitochondrial genomes lend support to its existence as a discrete and novel species (14). Of note, the term "*Candidatus*" is used primarily in bacterial taxonomy for those isolates that have yet to be cultured and is not used in zoological nomenclature. We are including this organism in this review so the audience is aware of a possible new species of *Dirofilaria* in Asia.

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