



Exploring challenges in Giardia cyst visualisation by common microscopy methods

Fava, N. D. M. N., Silva, K. J. S., Souza Freitas, B. L., Rodrigues da Cunha, M. J., Belini, V. L., Dooley, J. S. G., Fernandez-Ibañez, P., Byrne, J. A., & Sabogal-Paz, L. P. (2023). Exploring challenges in Giardia cyst visualisation by common microscopy methods. *Water Practice & Technology*.
<https://doi.org/10.2166/wpt.2023.008>

[Link to publication record in Ulster University Research Portal](#)

Publication Status:

Published online: 25/01/2023

DOI:

[10.2166/wpt.2023.008](https://doi.org/10.2166/wpt.2023.008)

Document Version

Publisher's PDF, also known as Version of record


General rights

Copyright for the publications made accessible via Ulster University's Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The Research Portal is Ulster University's institutional repository that provides access to Ulster's research outputs. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact pure-support@ulster.ac.uk.

Exploring challenges in *Giardia* cyst visualisation by common microscopy methods

Natália de Melo Nasser Fava^a, Kamila Jessie Sammarro Silva^{a,b}, Bárbara Luíza Souza Freitas^a, Maria Júlia Rodrigues da Cunha^a, Valdinei Luís Belini^c, James Stephen Gerard Dooley^d, Pilar Fernandez-Ibañez^e, John Anthony Byrne^e and Lyda Patricia Sabogal-Paz ^{a,*}

^a Department of Hydraulics and Sanitation, São Carlos School of Engineering, University of São Paulo, Avenida Trabalhador São-Carlense, 400. São Carlos, São Paulo 13566-590, Brazil

^b São Carlos Institute of Physics, University of São Paulo, Avenida Trabalhador São-Carlense, 400. São Carlos, São Paulo 13566-590, Brazil

^c Department of Electrical Engineering, Federal University of São Carlos, Rodovia Washington Luís, km 235. São Carlos, São Paulo 13566-905, Brazil

^d Nutrition Innovation Center for Food and Health (NICHE), School of Biomedical Sciences, Ulster University, Coleraine, Northern Ireland BT52 1SA, United Kingdom

^e Nanotechnology and Integrated Bioengineering Centre, School of Engineering, Ulster University, Jordanstown, Northern Ireland BT37 0QB, United Kingdom

*Corresponding author. E-mail: lysaboga@sc.usp.br

 LPS-P, 0000-0003-2753-3248

ABSTRACT

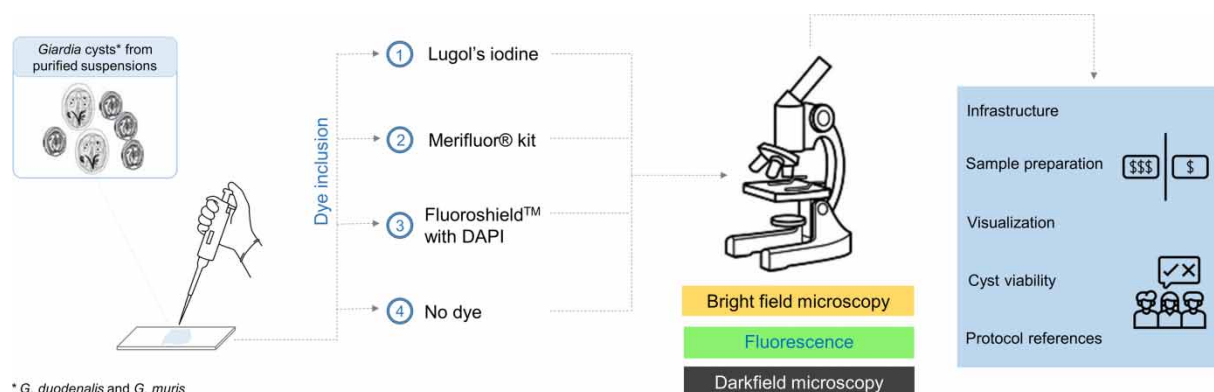
Giardia spp. is an intestinal parasite responsible for worldwide disease outbreaks. Guiding researchers and practitioners to choose among current methods for microscopy detection of the infectious forms may be directly beneficial to public health and the environment. This study provides an overall comparison of brightfield (BF), fluorescence and darkfield (DF) microscopies for detecting *Giardia duodenalis* and *Giardia muris* cysts, by illustrating micrographs of such protocols applied to purified samples, as well as discussing advantages and constraints based on secondary information and collected data. BF analysis included Lugol's iodine staining. In fluorescence microscopy, samples were processed by immunofluorescence assay (IFA) with DAPI and by standalone DAPI dye. Cyst suspensions were also analysed by DF microscopy using a recently developed low-cost system. The three techniques enabled detecting *Giardia* spp. cysts, although they did not provide species identification by morphology. The overview of each method points out some relevant aspects to consider when selecting common optical microscopy techniques, and includes challenges and advantages regarding each of them.

Key words: darkfield, immunofluorescence, Lugol's iodine, optical microscopy, waterborne protozoa

HIGHLIGHTS

- Comparisons of BF, DF, standalone DAPI and IFA-combined are provided.
- BF and DF may be alternatives for low-cost detection of *Giardia* cysts.
- Combinations of at least two diagnostic methods are recommended to minimise inherent errors.

GRAPHICAL ABSTRACT



This is an Open Access article distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0), which permits copying, adaptation and redistribution, provided the original work is properly cited (<http://creativecommons.org/licenses/by/4.0/>).

1. INTRODUCTION

For a long time, water, sanitation, and hygiene (WASH) practitioners and regulating bodies have relied heavily on indicator microorganisms for many of their decisions, particularly in developing nations. However, recent studies have indicated that total reliance on faecal indicator bacteria may be misleading, since this group is often less persistent and more easily inactivated during treatment processes than other organisms, including the protozoa *Giardia* spp. (Mraz *et al.* 2021).

Giardia duodenalis is one of the commonest intestinal parasites that infects humans worldwide (Yason & Rivera 2007). From 2011 to 2016, 37% of worldwide waterborne protozoa outbreaks were caused by this zoonotic protozoan (Efstratiou *et al.* 2017). The chlorine-resistance characteristic combined with cysts' ability to permeate filtration units because they are small (6–15 μm) can explain the occurrence of giardiasis epidemics after consumption of treated drinking water in several countries (Smith 1998; Omarova *et al.* 2018). This illustrates the importance of considering this pathogen when making decisions regarding water and sanitation, as well as including it in regular monitoring of water systems, either conventional or point-of-use. The latter, particularly, is very important in low-income and self-supplied regions, which are more likely to be contaminated than others (Genter *et al.* 2021).

Because of the typical cyst morphology that avoids mistaking *Giardia* for other organisms, optical microscopy is still the main methodology used routinely to detect this organism in water, food, and faecal samples (Adeyemo *et al.* 2018). In addition, as it is low-cost (compared to molecular-based tools) and relatively easy to run, this sort of technique is the most suitable for developing countries (Tangtrongsup & Scorza 2010).

Brightfield (BF) microscopy associated with Lugol's iodine stain is considered the gold standard methodology for detecting cysts in stool samples (Hooshyar *et al.* 2019). It enhances the internal structures of cysts, which stand out from the other materials on the slide (Tangtrongsup & Scorza 2010). Nevertheless, in the field of water and sanitation, the standard protocol is direct immunofluorescence assay (IFA). This technique consists of adding fluorescent-labelled antibodies that will link specifically to the cysts' wall producing a bright fluorescence that can be observed in the microscope (USEPA 2012, 2014). For confirmation, it has been suggested that DAPI (4',6-diamidino-2-phenylindole) must be applied at the same time as the IFA test (USEPA 2012). The stain highlights the nuclei when it binds to DNA (USEPA 2012).

More recently, Belini *et al.* (2018) showed that darkfield (DF) microscopy was effective in detecting *Giardia* spp. in purified suspensions. This illumination technique is based on the formation of a hollow cone of light that encloses the objective lens, causing the light to bypass them. Thus, only diffracted/scattered light from objects in the mounting medium enters the objective lens, forming bright white structures against a dark background (Murphy 2001).

Despite the variety of microscopy techniques for *Giardia* cyst detection, selecting the most suitable method still poses a challenge, especially for practitioners. Therefore, this study aimed to explore, under controlled conditions, common methods for detecting *Giardia* spp. cysts, shedding light onto the possibilities for choosing protocols for detecting this parasite.

2. METHODS

2.1. *Giardia* cysts

Purified suspensions of *Giardia duodenalis* (200 cysts μL^{-1}) and *Giardia muris* cysts (149 cysts μL^{-1}) (Waterborne, Inc., New Orleans, USA) were used for microscopy. Although *G. duodenalis* is the only species considered pathogenic to humans, the rodent-exclusive pathogen, *G. muris* has been used as a model for *G. duodenalis* since their morphologies are similar (Haas & Kaymak 2003), making it also relevant to environmental, water and sanitation studies.

Aliquots of 5 μL of each suspension were spiked together onto flat glass microscopy slides for three different preparations – see below. The procedure was repeated for each species on an individual slide.

2.2. Microscopy visualisation and imaging

For BF microscopy, one drop of Lugol's iodine was added to the slides. *G. duodenalis* and *G. muris* identity were confirmed based on characteristics of cyst size (7–10 μm long \times 8–12 μm wide) and internal structures, according to classic literature description (Filice 1952; Jakubowski 1984).

As for fluorescence microscopy, spiked samples were kept dry overnight. Then, as recommended in Method 1623.1 (USEPA 2012), IFA was performed using the Merifluor[®] kit (Meridian Bioscience, Inc.), according to the manufacturer's recommendations. When using this kit, *Giardia* cysts appear as brilliant apple green fluorescence objects under ultraviolet light, with a typical size and an oval to round shape (USEPA 2012).

To visualise the cysts' nucleus, two drops of Fluoroshield[™] with DAPI (Sigma-Aldrich[®]) were added and incubated for 10 min at room temperature. This reagent stains the cysts a light blue internally, staining up to four distinct nuclei with a green rim or highlight (USEPA 2012). A second fluorescence microscopy process involved a simpler preparation method using only Fluoroshield[™] with DAPI.

An epifluorescence microscope (BX51, Olympus[®]) was used for both BF and fluorescence microscopy. Use of the former involved conventional staining with Lugol's iodine and observation of the organisms' structures under visible light using a 40× objective lens. The latter involved the use of FITC and DAPI as optical filters (Table 1) for visualising cysts and nuclei, respectively. Physical dimensions determined on Image-Pro[®] 6.3 were compared to reported patterns for *Giardia* cysts, according to USEPA (2012).

Table 1 | Optical filter specifications used in the Olympus BX51 microscope

Optical filter	Wavelength (nm)	Excitation wavelength (nm)	Emission wavelength (nm)
FITC	570	460–490	520
DAPI	400	330–385	420

DF images were acquired by adapting the standard microscope using an inexpensive, custom-made DF setup developed by Belini *et al.* (2018). A dry objective lens (Olympus BX41TF) and a charge-coupled device camera (Samsung[®] SDC313) were used. Image capture was carried out on PixelView[®]. Knowledge of the cysts' characteristic morphological features improved *Giardia* detection accuracy (Belini *et al.* 2018).

3. RESULTS AND DISCUSSION

3.1. Lugol's iodine staining under BF

As shown in Figure 1, this technique simplifies reliable identification of *Giardia* cysts by determining additional criteria besides size and shape. Using Lugol's iodine, *Giardia* spp. cysts, their double walls (thick arrows) and one internal structure (axoneme indicated by the narrow arrow) can be seen (Figure 1(a) and 1(b)). Occasionally, when comparing *Giardia* cysts, their size appears to be a consistent indicator for identification against different organisms. However, as *G. duodenalis* and *G. muris* share the same dimension spectra they cannot be differentiated between themselves.

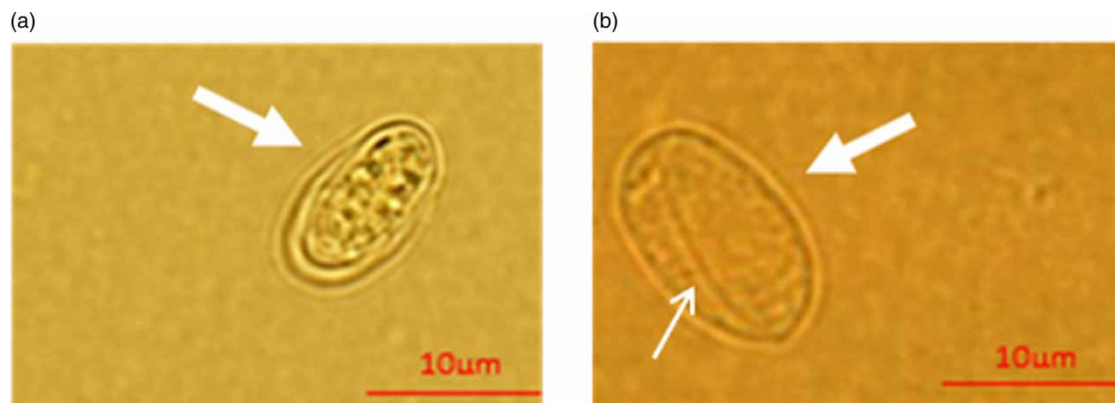


Figure 1 | Microscopic images of (a) *Giardia muris* and (b) *Giardia duodenalis* with Lugol's iodine acquired under BF. Thick arrows point to cyst walls and the narrow arrow to an axoneme.

Although Lugol's iodine is the most used dye in routine laboratory diagnostics, its use requires an expert to identify organisms and their typical structures (Charakova 2010). Furthermore, internal quality control of the working iodine solution must be performed regularly on known reference organisms to ensure the performance of the stain (Dalynn Biologicals 2005). As staining is not selective, this method hinders cyst detection in environmental samples, which are likely to contain debris and therefore require concentration and purification steps, and deep reliance on the microscopist's subjective analysis.

3.2. Immunofluorescence assay and DAPI staining

Figure 2(a) displays a clear *Giardia* cyst (narrow arrow) visualised under FITC filter block. This result was confirmed by DAPI, which exhibited intense blue internal staining (Figure 2(b)). Thicker arrows in this micrograph also suggested the presence of cysts, but differences in the fluorescence signal led to doubt. As DAPI staining is not as specific as FITC-fluorescence, considering interferences, separate samples were prepared to evaluate the particularities of each species.

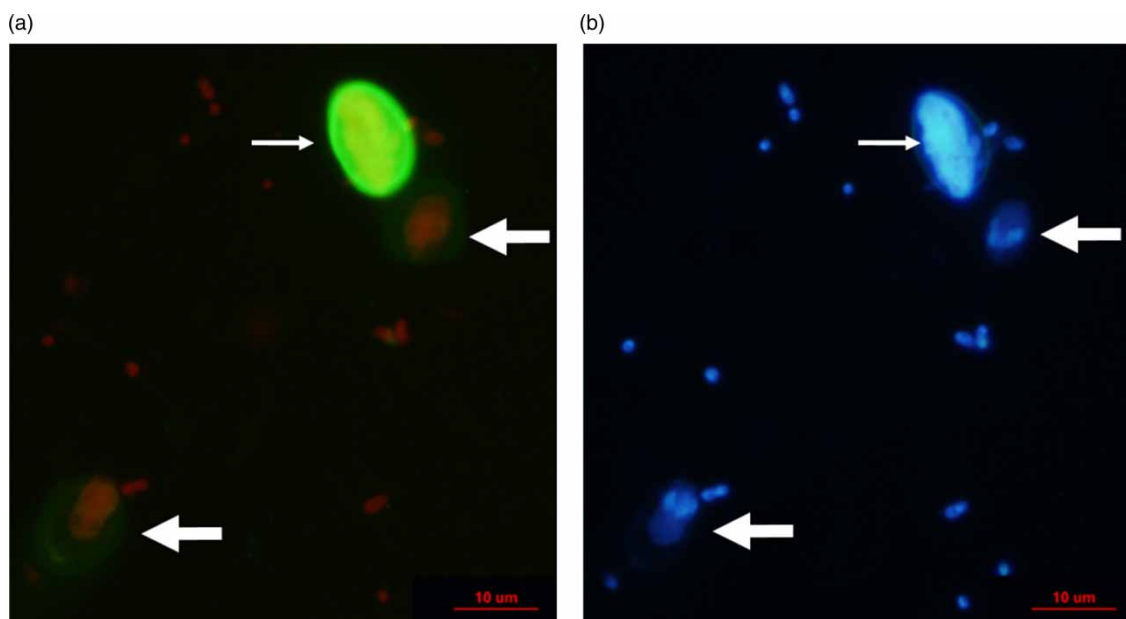


Figure 2 | Visualisation of a mixed sample under (a) FITC and (b) DAPI. Narrow arrows point to *Giardia duodenalis* cysts visualised as expected and thick arrows to possible *Giardia muris* cysts.

Figure 3 shows *G. duodenalis* cysts under FITC (a) and DAPI (b), compared to *G. muris* under the same filters (c and d, respectively). *G. muris* fluorescence intensity was clearly lower than that in *G. duodenalis* (Figure 3(a) and 3(c)), suggesting that observations indicated by thick arrows in Figure 2 referred to *G. muris*.

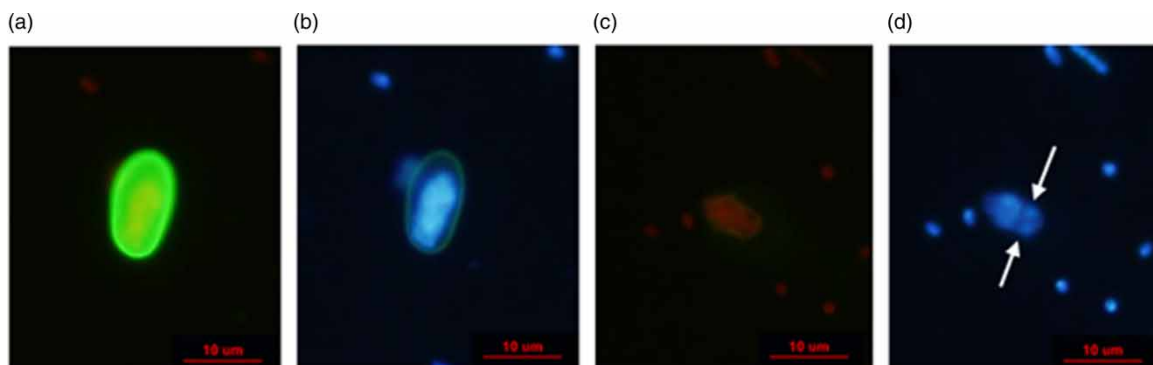


Figure 3 | Difference in *Giardia* cyst fluorescent dye uptake: *Giardia duodenalis* visualised under (a) FITC and (b) DAPI; *Giardia muris* under (c) FITC and (d) DAPI. Narrow arrows indicate the nuclei of *Giardia muris*.

Despite the high sensitivity and specificity of Merifluor[®], its datasheet indicates that the kit is recommended for use on faecal human samples, in which *G. duodenalis* is, possibly, the only species present. Therefore, the monoclonal antibodies of the kit are likely to be specific to *G. duodenalis* antigens. This assumption could explain the difference in fluorescence intensity between the two species but could also be a limiting factor for the kit's use in environmental matrices, since there is no assurance which species might be present in the sample (Edelstein & Edelstein 1989; Alderisio *et al.* 2017). From a public health perspective, this is particularly important, as differences in fluorescence staining may mislead reported cyst occurrences and concentrations in environmental samples (Alderisio *et al.* 2017).

Still in that sense, although FITC-characteristic fluorescence was unclear for *G. muris* (Figure 3(c)), two nuclei were observed clearly (Figure 3(d)), implying that Fluoroshield[™] with DAPI exclusive staining could represent an alternative for distinguishing *G. duodenalis* from *G. muris*. However, when this hypothesis was tested, it was found that DAPI fluorescence declines over time when applied as a standalone dye (Figure 4(a)–4(c)). This confirms that a successful IFA protocol must include fluorescent-labelled antibodies and DAPI (USEPA 2012). That should also be taken into account for different matrices. If IFA readings in purified suspensions are misleading, this challenge is likely to be even harder for environmental samples.

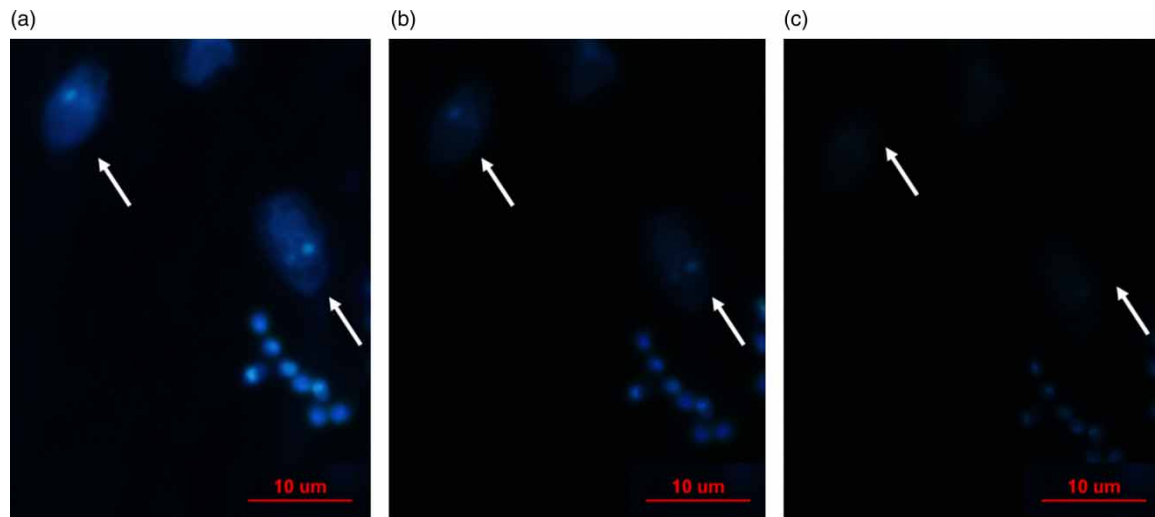


Figure 4 | Staining loss of *Giardia muris* cysts labelled with Fluoroshield[™] with DAPI (a) immediately after UV exposure, (b) 6 min after UV exposure, and (c) 12 min after UV exposure. Narrow arrows point to cysts.

It is noted that IFA refers to the current protocol established by USEPA methods 1623.1 and 1693 for analysis of water and disinfected wastewater (2012, 2014), thus it is assumed to be the first resource WASH practitioners would rely on for periodically monitoring quality considering protozoan parasites. In fact, several studies on environmental samples that do not have a standardised detection method include IFA (Olson *et al.* 1999; Greinert *et al.* 2004; Graczyk *et al.* 2008; Grit *et al.* 2012; Giglio & Sabogal-Paz 2018; Sammarro-Silva & Sabogal-Paz 2020, 2021a, 2021b; Ogura & Sabogal-Paz 2021, 2022). The motive for choosing this protocol is assumed to be its high sensitivity, as older references that consider complex matrices were also immunofluorescence-based, as in Olson *et al.* (1999), which used IFA to quantify the survival of cysts seeded into soil and cattle waste.

3.3. Darkfield

Image results obtained for transmitted DF illumination demonstrated that, despite being unable to differentiate *G. duodenalis* from *G. muris*, DF microscopy allowed them to be distinguished by their typical oval shape from other illuminated elements. These interferers are particles that are smaller than the diffraction resolution limit for conventional light microscopy (~200 nm) (Murphy 2001).

An example retrieved DF micrograph is shown in Figure 5. The arrows point to *Giardia* cysts but it is not possible to identify their species. (The poor resolution is due to the imaging equipment, as different setups were used for BF and DF in this study.)



Figure 5 | *Giardia* cysts under transmitted darkfield illumination. Arrows point to cysts.

DF imaging can be accomplished in conventional light microscopes equipped with commercially available accessories or, as in the case of Belini *et al.* (2018), with a low-cost, easy-to-use ring illuminator built with standard light-emitting diodes. By using transmitted DF illumination, the authors observed well-defined cyst walls and intracellular structures, including nuclei and retracted cytoplasm, while axonemes were only imaged in the reflected DF mode. These results encourage further use of transmitted DF microscopy in *Giardia* spp. visualisation.

DF microscopy is supported mainly by its low-cost and lack of need for reagents, dyes, or specific equipment (Belini *et al.* 2018). So, it might be an alternative for detecting *Giardia* spp. cysts in resource-poor settings. However, in a general scenario contemplating environmental samples, scattering of other particles may hinder visualisation, particularly if the slide contains debris, thus purification methods would apply just as they do in all protocols mentioned above. Like Lugol's iodine in BF, DF effectiveness depends on well-trained observers. Due to possible microscopist subjectiveness, it is recommended that at least two professionals analyse samples for quantification.

3.4. Overview of cyst visualisation techniques under optical microscopy

Table 2 summarises general properties of BF, DF, and fluorescence protocols. These may be either advantages or limitations depending on circumstances – e.g., laboratory settings, available resources and level of urgency for cyst detection/analysis, personnel, matrix quality, etc. On the basis of both the micrographs obtained in this study and experience, the combination of techniques is believed to be an alternative to deal with the constraints inherent in individual methods. If more than one observer is available, that is also important to avoid bias in slide interpretation, as well as human error, as all the procedures cited above are observer-dependent.

4. CONCLUSIONS

Selecting a microscopy imaging method for *Giardia* cyst identification depends on several factors, including available laboratory infrastructure and human resources, professional expertise, the matrix to be analysed, and time. Still, protocols that require bulky equipment and costly reagents may be challenging.

An exploratory approach was used to demonstrate that BF, DF, and IFA (combined or not with DAPI) enable *Giardia* spp. cyst detection in purified samples, despite not providing species identification. This suggests that simple and inexpensive techniques such as BF and DF microscopy may be useful in low- and middle-income countries when IFA protocols cannot be performed, if validation is carried out.

Table 2 | Overview of three microscopy techniques for *Giardia* detection considering sample processing, visualisation, and additional features

Category	Brightfield	Darkfield	Fluorescence (IFA; DAPI)
Infrastructure ^a	Conventional light microscope	Low-cost adaptation of conventional light microscope ^b	Epifluorescence microscope equipped with FITC and DAPI optical filters; incubator for 37 °C
Sample preparation	Easy to run; inexpensive reagent; rapid preparation; samples need to be analysed immediately after preparation	Label-free; immediate reading	Needs to be performed in absence of direct light; easy to run, but preferably performed by experts; commercial kits are available; requires up to 4 h for sample drying and 30 min incubation
Visualisation	Not selective; allows visualisation of internal structures under 1,000× magnification; hindered by debris; requires experts	Not selective; allows visualisation of internal structures under 1,000× magnification; highly hindered by debris; requires experts	IFA: selective staining; easy to identify against background; hardly affected by debris; may underestimate concentration due to low signal of <i>G. muris</i> ^c ; staining lasts up to 7 days if stored in absence of light at 4 °C; does not require experts. DAPI: not selective; may be useful as confirmatory method; quickly loses fluorescence; requires experts
Cyst viability	Cyst viability may be assessed by additional staining ^d	N/A	Cyst viability may be assessed by a variety of fluorescent probes commercially available ^d
Protocol references	Standard analysis for stool samples ^e	New method ^b	USEPA reference method for water and disinfected wastewater analysis ^f

Note: DAPI, 4',6-diamidino-2 phenylindole; N/A, information not available.

^aConsidered within the scope of sample preparation and analysis, i.e., it consider neither concentration nor purification.

^bBelini *et al.* (2018).

^cLow signal found in this study and by Alderisio *et al.* (2017).

^dSammarro-Silva & Sabogal-Paz (2021a, 2021b).

^eHooshyar *et al.* (2019).

^fUSEPA (2012, 2014).

Ideally, analysis for *Giardia* cyst detection should include a combination of at least two techniques, so that constraints are compensated for. Additionally, microscopy samples should preferably be analysed by different professionals, with repetitions, for more reliable results. This is important, particularly in environmental analyses, in which interferences and different species of pathogens may be present, nonetheless, it would increase sample processing costs considerably depending on the method.

FUNDING

This work was supported by the São Paulo Research Foundation – FAPESP (Process 12/50522-0), The Royal Society (ICA\R1\201373 – International Collaboration Awards 2020), and National Council for Scientific and Technological Development (CNPq-Brazil, process no. 308070/2021-6). The Coordination for the Improvement of Higher Education Personnel (PNPD/CAPES) awarded a fellowship to M.J.R.d.C.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

- Adeyemo, F. E., Singh, G., Reddy, P. & Stenstrom, T. A. 2018 Methods for the detection of *Cryptosporidium* and *Giardia*: from microscopy to nucleic acid-based tools in clinical and environmental regimes. *Acta Trop.* **184**, 15–28.
- Alderisio, K. A., Villegas, L. F., Ware, M. W., McDonald, L. A., Xiao, L. & Villegas, E. N. 2017 Differences in staining intensities affects reported occurrences and concentrations of *Giardia* spp. in surface drinking water sources. *J. Appl. Microbiol.* **123**(6), 1607–1613.
- Belini, V. L., Freitas, B. L. S., Sabogal-Paz, L. P., Branco, N. & Franco, R. M. B. 2018 Label-free darkfield-based technique to assist in the detection of *Giardia* cysts. *Water Air Soil Pollut.* **229**, 195.
- Charakova, B. 2010 Comparative evaluation of the diagnostic methods for detection of *Giardia duodenalis* in human fecal samples. *J. Sci.* **8**, 174–179.
- Dalynn Biologicals 2005 *Lugol's Iodine Stain. Catalogue n SL95*. Available from: http://www.dalynn.com/dyn/ck_assets/files/tech/SL95.pdf. (accessed 25 March 2019).
- Edelstein, P. H. & Edelstein, M. A. C. 1989 Evaluation of the Merifluor-Legionella immunofluorescent reagent for identifying and detecting 21 legionella species. *J. Clin. Microbiol.* **27**, 2455–2458.
- Efstratiou, A., Ongerth, J. & Karanis, P. 2017 Evolution of monitoring for *Giardia* and *Cryptosporidium* in water. *Water Res.* **123**, 96–112.
- Filice, F. P. 1952 Studies on the cytology and life history of a *Giardia* from the laboratory rat. *Univ Calif. Publ. Zool.* **57**, 53–146.
- Genter, F., Willetts, J. & Foster, T. 2021 Faecal contamination of groundwater self-supply in low- and middle- income countries: systematic review and meta-analysis. *Water Res.* **201**, 117350.
- Giglio, G. L. & Sabogal-Paz, L. P. 2018 Performance comparison of three methods for detection of *Giardia* spp. cysts and *Cryptosporidium* spp. oocysts in drinking-water treatment sludge. *Environ. Monit. Assess.* **190**, 686.
- Graczyk, T. K., Kacprzak, M., Neczaj, E., Tamang, L., Graczyk, H., Lucy, F. E. & Girouard, A. S. 2008 Occurrence of *Cryptosporidium* and *Giardia* in sewage sludge and solid waste landfill leachate and quantitative comparative analysis of sanitization treatments on pathogen inactivation. *Environ. Res.* **106**(1), 27–33.
- Greiner, J. A., Furtado, D. N., Smith, J. J., Monte Barardi, C. R. & Simões, C. M. O. 2004 Detection of *Cryptosporidium* oocysts and *Giardia* cysts in swimming pool filter backwash water concentrates by flocculation and immunomagnetic separation. *Int. J. Environ. Health Res.* **14**, 395–404.
- Grit, G. H., Bénére, E., Ehsan, A., De Wilde, N., Claerebout, E., Vercruyse, J., Maes, L. & Geurden, T. 2012 *Giardia duodenalis* cyst survival in cattle slurry. *Vet Parasitol.* **184**, 330–334.
- Haas, C. N. & Kaymak, B. 2003 Effect of initial microbial density on inactivation of *Giardia muris* by ozone. *Water Res.* **37**, 2980–2988.
- Hooshyar, H., Rostamkhani, P., Arbabi, M. & Delavari, M. 2019 *Giardia lamblia* infection: review of current diagnostic strategies. *Gastroenterol. Hepatol. Bed Bench* **12**, 3–12.
- Jakubowski, W., 1984 Detection of *Giardia* cysts in drinking water: state of the art. In: *Giardia and Giardiasis* (Stanley, L. E. & Ernest, A. M., eds). Plenum Press, New York, USA, pp. 263–286.
- Mraz, A. L., Tumwebaze, I. K., McLoughlin, S. R., McCarthy, M. E., Verbyla, M. E., Hofstra, N., Rose, J. B. & Murphy, H. M. 2021 Why pathogens matter for meeting the United Nations' sustainable development goal 6 on safely managed water and sanitation. *Water Res.* **189**, 116591.
- Murphy, D. B. 2001 *Fundamentals of Light Microscopy and Electronic Imaging*. Wiley-Liss, New York, USA, pp. 112–116.
- Ogura, A. P. & Sabogal-Paz, L. P. 2021 Detection and alkaline inactivation of *Cryptosporidium* spp. oocysts and *Giardia* spp. cysts in drinking-water treatment sludge. *J. Water Process Eng.* **40**, 101939.
- Ogura, A. & Sabogal-Paz, L. P. 2022 Direct centrifugation for detecting *Giardia* spp. cysts in filter backwash water. *J. Water Sanit. Hyg. Dev.* **2**(6), 475–484.
- Olson, M. E., Go, J., Phillips, M., Guselle, N. & McAllister, T. A. 1999 *Giardia* Cyst and *Cryptosporidium* Oocyst survival in water, soil, and cattle feces. *J. Environ. Qual.* **28**, 1991–1996.
- Omarova, A., Tussupova, K., Berndtsson, R., Kalishev, M. & Sharapatova, K. 2018 Protozoan parasites in drinking water: a system approach for improved water, sanitation and hygiene in developing countries. *Int. J. Environ. Res. Public Health* **15**, 495.
- Sammarro-Silva, K. J. & Sabogal-Paz, L. P. 2020 *Giardia* spp. cysts and *Cryptosporidium* spp. oocysts in drinking water treatment residues: comparison of recovery methods for quantity assessment. *Environ. Technol.* **42**(20), 3144–3153.
- Sammarro-Silva, K. J. & Sabogal-Paz, L. P. 2021a Ferric sulphate flocculation as a concentration method for *Giardia* and *Cryptosporidium* in filter backwash water. *Water Pract. Technol.* **16**(2), 557–565.
- Sammarro-Silva, K. J. S. & Sabogal-Paz, L. P. 2021b *Cryptosporidium* spp. and *Giardia* spp. (oo)cysts as target-organisms in sanitation and environmental monitoring: a review in microscopy-based viability assays. *Water Res.* **189**, 116590.
- Smith, H. V. 1998 Detection of parasites in the environment. *Parasitology* **117**, 113S–141S.
- Tangtrongsup, S. & Scorza, V. 2010 Update on the diagnosis and management of *Giardia* spp. infections in dogs and cats. *Top. Companion Anim. Med.* **25**, 155–162.
- USEPA 2012 *Method 1623.1: Cryptosporidium and Giardia in Water by Filtration/IMS/FA*. Office of Ground Water and Drinking Water, Washington, DC, USA.

- USEPA 2014 *Method 1693: Cryptosporidium and Giardia in Disinfected Wastewater by Concentration/IMS/IFA*. Office of Ground Water and Drinking Water, Washington, DC, USA.
- Yason, J. A. & Rivera, W. L. 2007 [Genotyping of *Giardia duodenalis* isolates among residents of slum area in Manila, Philippines](#). *Parasitol. Res.* **101**, 681–687.

First received 24 November 2022; accepted in revised form 12 January 2023. Available online 25 January 2023