Comparison of Levels of Inactivation of Two Isolates of *Giardia lamblia* Cysts by UV Light

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The effects of 254-nm UV irradiation on two human isolates (WB and H3) of *Giardia lamblia* cysts were assessed using a collimated beam protocol and a Mongolian gerbil model. The levels of infection of cysts in the gerbils were assessed based on the presence of cysts in feces and the presence and activity of trophozoites in the small intestine of inoculated gerbils. The results suggest that there were differences in the infectivities of the WB and H3 isolates, as well as in susceptibilities of the parasites to UV light. Without UV exposure, gerbils were more readily infected by isolate H3 cysts. After UV exposure of the cysts, however, the gerbils were more susceptible to isolate WB cysts.

*Giardia lamblia* (also referred to as *Giardia duodenalis*) is the most commonly identified protozoan parasite in worldwide outbreaks of waterborne disease and causes between 100,000 and 2.5 million cases a year in the United States (15). Many of these giardiasis outbreaks are associated with municipal drinking water supplies which meet regulatory standards for turbidity and coliforms and occur in water systems using a surface water source (11).

Early studies suggested that *G. lamblia* cysts were resistant to UV irradiation at the fluences commonly used by commercial UV treatment units when the viability of cysts was assessed by the in vitro excystation surrogate assay (26). However, Craik et al. (10) found that in vitro excystation and nucleic acid staining assays grossly underestimate inactivation of *G. muris* compared to the reduction in infectivity measured in a mouse model. Other researchers have since reported significant (i.e., >99%) inactivation of *G. lamblia* cysts, as measured by infectivity in Mongolian gerbils, at UV doses readily achievable in water treatment procedures (7, 19, 22).

Clancy et al. (8) concluded that five isolates of *Cryptosporidium parvum* oocysts were equally sensitive to UV light. In contrast, no direct comparisons between the UV inactivation properties of different *Giardia* spp. isolates have been made. Marked differences in the biological behaviors and host responses in gerbils of antigenically distinct *Giardia* spp. isolates have been reported (1). Faubert et al. (13) compared the patterns of infection of human isolates and animal isolates of *G. lamblia* in Mongolian gerbils and found that the pattern of cyst release in these animals was a characteristic of the parasite and was independent of the host. There have been no studies that have dealt with the potential impact of biological differences between *Giardia* isolates on the infectivity of UV-irradiated cysts and the inactivation by UV irradiation.

*Giardia lamblia* isolate WB and Wallis (7) reported up to a 2-log_{10} reduction in the infectivity in Mongolian gerbils of human-derived *G. lamblia* isolate WB cysts that were exposed to a UV fluence of 10 mJ/cm² using a low-pressure mercury lamp. However, Linden et al. (19) reported a >4-log_{10} reduction in the infectivity of *G. lamblia* isolate CH-3 cysts at a UV fluence of 1 mJ/cm² based on the infectivity in Mongolian gerbils. The apparent differences in UV sensitivity reported in these two studies may have been due to differences in the *G. lamblia* strains or to other variables, such as differences in cyst purification procedures, water matrix characteristics, UV exposure procedures, and procedures for assessing infectivity in gerbils. The objective of this research was to compare directly the UV inactivations of cysts of two human isolates of *G. lamblia* (isolates WB and H3) using a Mongolian gerbil model and identical UV exposure procedures.

**MATERIALS AND METHODS**

**Parasites.** Cysts of two human isolates of *G. lamblia* were used in this study. Strain WB *G. lamblia* trophozoites were obtained from the American Type Culture Collection (ATCC 30957). This strain was originally isolated from a patient in Afghanistan with chronic symptomatic giardiasis and belongs to assembly A (23). Purified *G. lamblia* isolate WB cysts were obtained by infecting Mongolian gerbils with cultured trophozoites of *G. lamblia* isolate WB as described elsewhere (4). Gerbils were inoculated orally with 0.2 ml of phosphate-buffered saline containing ~1 × 10⁶ *G. lamblia* trophozoites. Feces were collected from the gerbils for 2 h and were purified using sucrose flotation as described elsewhere (14). Briefly, the emulsified feces were layered over a 1 M sucrose solution and centrifuged at 500 × g for 10 min at 4°C. The cyst-rich layer at the sucrose-water interface was collected and washed three times in deionized water by centrifugation at 500 × g for 10 min at 4°C.

Strain H3 *G. lamblia* cysts originated from H. Stibbs at Waterborne Inc., New Orleans, LA, and were a kind gift from G. M. Faubert at McGill University, Montreal, Quebec, Canada. Isolate H3 belongs to assembly B (16). The cysts were maintained by passage through Mongolian gerbils every 2 weeks. The cyst purification procedure was the same as that described above for isolate WB cysts. All cysts collected daily were stored at 4°C and were used in experiments within 5 days after collection.

**UV exposure.** Up to 2 × 10⁶ *G. lamblia* cysts purified from gerbil fecal samples were suspended in 20 ml of deionized water in 55-mm-diameter glass petri dishes to obtain a suspension containing approximately 10⁷ cysts/ml. The suspension depth was 10.5 mm. The suspensions were exposed to controlled fluences of UV from a 10-W low-pressure mercury arc lamp using a collimated beam apparatus (Rayox; Calgon Carbon Corporation). The suspensions were stirred continuously...
during the exposure. The irradiance at the surface of the liquid was measured using a calibrated radiometer (P-9710; Gigahertz Optik Inc., Newburyport, MA). The UV absorbance at 254 nm of each experimental cyst suspension was determined using a spectrophotometer, and the values ranged from 0.05 to 0.09 for a 10-mm path length, depending on the purity of the fecal cyst preparation. The depth-averaged UV fluence rate was determined by correcting the UV irradiance measurement for radial variation of the UV beam, refraction at the air interface, and absorbance within the liquid. Detailed procedures are described elsewhere (9).

The depth-averaged UV fluence rate was determined by correcting the UV irradiance using a calibrated radiometer (P-9710; Gigahertz Optik Inc., Newburyport, MA).

VOL. 73, 2007 UV INACTIVATION OF TWO ISOLATES OF G. LAMBLIA CYSTS

### Table 1. Dose-response analysis of G. lamblia cysts in Mongolian gerbils indicating the intensity of infection

| Strain | Inoculum (cysts/gerbil) | Total no. of trials | Total no. of gerbils inoculated | Total no. of gerbils infected | No. of gerbils with: | Proportion of gerbils infected |
|--------|-------------------------|---------------------|--------------------------------|-----------------------------|---------------------|-----------------------------|
|        |                         |                     |                                |                             | Strong infection     | Moderate infection       | Weak infection         |
|        |                         |                     |                                |                             | 1                   | 0                          | 3                        | 0.25                     |
| H3     | 10                      | 3                   | 16                             | 4                           | 1                   | 0                          | 3                        | 0.25                     |
|        | 100                     | 5                   | 18                             | 16                          | 14                  | 1                          | 1                        | 0.89                     |
|        | 1,000                   | 3                   | 10                             | 10                          | 10                  | 0                          | 0                        | 0                        |
|        | 10,000                  | 1                   | 5                              | 5                           | 5                   | 0                          | 0                        | 1                        |
| WB     | 100                     | 4                   | 16                             | 7                           | 1                   | 0                          | 6                        | 0.44                     |
|        | 1,000                   | 4                   | 16                             | 11                          | 1                   | 1                          | 9                        | 0.69                     |
|        | 10,000                  | 4                   | 16                             | 15                          | 13                  | 1                          | 1                        | 0.94                     |

Calculations. The dose response of G. lamblia cysts in Mongolian gerbils was quantified using a logistic dose-response model developed by Finch et al. (14):

\[ \text{logit} = \beta_1 + \beta_2 \log_{10}(d) \]  

where \( \text{logit} = \ln[P/(1 - P)] \), where \( P \) is the proportion of animals infected, \( d \) is the number of infectious cysts in the oral inoculum, and \( \beta_1 \) and \( \beta_2 \) are logistic model parameters estimated by carrying out dose-response experiments with the gerbils and analyzing the outcome using the maximum likelihood method as described by Gyurcik et al. (17). \( \beta_1 \) and \( \beta_2 \) determined for the WB and H3 isolates in the dose-response experiments were used to estimate the number of infectious cysts remaining following UV exposure. After a UV experiment, \( P \) was determined based on the gerbil infectivity results, \( d \) was calculated using equation 1, and the level of inactivation was determined as follows:

\[ \text{inactivation} = -\log_{10}(d/d_0) \]

where \( d_0 \) is the total number of cysts in the inoculum estimated by hemocytometer counting.

### RESULTS

Dose-response data for Mongolian gerbils. To determine the infectivity of each isolate in the gerbils, several dose-response experiments were carried out with inoculum sizes ranging from \( 10^1 \) to \( 10^5 \) cysts per animal. The cohort sizes for each inoculum size in each experiment ranged from four to eight gerbils. The pooled results of these dose-response experiments are summarized in Table 1. The logit dose-response model parameters and the dose required for 50% infection (ID\(_{50}\)) were calculated based on the dose-response results in Table 1 and are shown in Table 2 for each isolate. The confidence intervals for each parameter estimate were calculated based on the 95% joint confidence region (17). The calculated ID\(_{50}\) for the WB isolate was 180 cysts, which is comparable to a previously reported ID\(_{50}\) for G. lamblia cyst infectivity in Mongolian gerbils (248 cysts) (14). The ID\(_{50}\) for the H3 isolate (22 cysts) was considerably lower. Based on the computed ID\(_{50}\), the H3 isolate was considerably more infectious to the gerbils than the WB isolate was. The 95% joint confidence regions of the dose-response parameters (\( \beta_1 \) and \( \beta_2 \)) for the two isolates (not shown) did not overlap, which indicates that the infectious properties of the WB and H3 isolates were significantly different at the 95% confidence level.

The gerbils were scored positive for infection based on the presence of either cysts in the feces or trophozoites in the intestine or both (Table 1). However, the intensity of infection, as determined by observation of cysts or trophozoites in gerbils

### Table 2. Mongolian gerbil logit dose-response model parameters with upper and lower 95% confidence intervals for G. lamblia cysts

| Isolate(s) | \( \beta_1 \) (95% confidence interval) | \( \beta_2 \) (95% confidence interval) | ID\(_{50}\)† | Reference |
|------------|----------------------------------------|----------------------------------------|------------|-----------|
| WB         | \(-3.06 (−3.89, −2.18)\)              | \(1.36 \ (1.07, 1.69)\)               | 180        | This study |
| H3         | \(-4.36 (−5.48, −3.24)\)              | \(3.25 \ (2.57, 4.11)\)               | 22         | This study |
| WB, CDC:0284:1, and 10 other isolates | \(-3.69 (−5.04, −2.37)\) | \(1.54 \ (0.89, 2.20)\) | 248        | 14        |

† ID\(_{50}\) = −antilog(−\( \beta_1 \)/\( \beta_2 \)).
that were positive, varied considerably, even between gerbils in the same cohort. For example, in some gerbils that were positive for infection, cysts were observed in the feces and many actively motile trophozoites were observed in the intestinal mucosal scrapings. In other gerbils, no cysts were observed in the feces and only a few inactive or nonmotile trophozoites were observed in the intestinal scrapings. The data for inactive or nonmotile trophozoites were confirmed based on size, shape, and nucleic acid staining and were considered evidence of infection in this study. To investigate the levels of infection further, gerbils that were positive for infection as shown in Table 1 were subdivided into three categories: gerbils in which cysts were observed in the feces and many active trophozoites were observed in the small intestine were considered to have a strong infection; gerbils in which no cysts were observed in the feces but live and active trophozoites were observed in the small intestine were considered to have a moderate infection; and gerbils in which no cysts were observed in the feces but inactive trophozoites were observed in the small intestine were considered to have a weak infection. All other gerbils were scored negative for infection. About 89% of the gerbils inoculated with 100 \( G. lamblia \) isolate H3 cysts were infected, and most of these gerbils had strong infections. In contrast, only 44% of the gerbils inoculated with 100 isolate WB cysts were infected, and most of these gerbils had weak infections. All gerbils inoculated with 1,000 isolate H3 cysts were strongly infected, while only 69% of the gerbils inoculated with 1,000 WB cysts were infected and in these animals most of the infections were weak. The isolate H3 cysts, therefore, were more infectious in the Mongolian gerbil host both based on the total numbers of gerbils that were positive for infection and the intensity of infection.

**UV fluence response.** \( G. lamblia \) isolate WB and H3 cysts were exposed to a constant UV fluence of 40 mJ/cm\(^2\) and inoculated into gerbils within 2 h after exposure. Four independent UV exposure experiments were carried with each isolate using different cyst preparations. The pooled results for each isolate are shown in Table 3. Table 3 shows the total number of infections and the distribution of the intensities of infections. Following UV exposure, the H3 isolate was less infectious in the gerbils than the WB isolate based on both the total number of infections and the intensity of infection. Only weak infections were observed in the gerbils inoculated with up to 100,000 UV-exposed H3 cysts, while some strong infections were observed in gerbils inoculated with 100,000 WB cysts and moderate infections were observed in gerbils inoculated with

### TABLE 3. UV dose-response results for \( G. lamblia \) cysts in Mongolian gerbils at a fluence of 40 mJ/cm\(^2\), indicating the intensity of infection\(^a\)

| Isolate | UV dose (mJ/cm\(^2\)) | Inoculum (cysts/gerbil) | No. of gerbils per dose | No. of gerbils infected | No. of gerbils with: | Proportion of gerbils infected |
|---------|-----------------------|------------------------|------------------------|------------------------|-----------------------|-------------------------------|
|         |                       |                        |                        |                        | Strong infection | Moderate infection | Weak infection |                     |
| WB      | 40                    | 10,000                 | 16                     | 8                      | 0                     | 1               | 7               | 0.5                  |
|         |                       | 100,000                | 16                     | 11                     | 4                     | 0               | 7               | 0.69                 |
| H3      | 40                    | 1,000                  | 10                     | 1                      | 0                     | 0               | 0               | 0.10                 |
|         |                       | 10,000                 | 24                     | 4                      | 0                     | 0               | 4               | 0.17                 |
|         |                       | 100,000                | 18                     | 4                      | 0                     | 0               | 4               | 0.22                 |

\(^a\) The data are pooled results of four UV exposure trials for each isolate.

### TABLE 4. Reduction of \( G. lamblia \) infectivity in Mongolian gerbils due to UV irradiation at a fluence of 40 mJ/cm\(^2\), indicating the intensity of infection\(^a\)

| Isolate | Trial | Inoculum (cysts/gerbil) | Total no. of gerbils inoculated | Total no. of gerbils infected\(^b\) | Proportion of gerbils infected | No. of infectious cysts | Level of inactivation\(^c\) | Mean level of inactivation\(^d\) |
|---------|-------|------------------------|--------------------------------|-----------------------------------|-----------------------------|-------------------------|---------------------------|-------------------------------|
| WB      | 1     | 10,000                 | 4                             | 1                                 | 0.25                        | 34                      | 2.5                       | 2.2                           |
|         | 2     | 10,000                 | 4                             | 3                                 | 0.75                        | 1,027                   | 2.0                       | 1.7                           |
|         | 3     | 10,000                 | 4                             | 2                                 | 0.5                         | 186                     | 1.7                       | 1.7                           |
|         | 4     | 10,000                 | 4                             | 3                                 | 0.75                        | 1,027                   | 1.7                       | 1.9                           |
| H3      | 2     | 100,000                | 6                             | 0                                 | 0.0                         | <7                      | >3.2                      | 4.2                           |
|         | 3     | 100,000                | 6                             | 1                                 | 0.17                        | 7                       | 4.2                       | 4.2                           |
|         | 4     | 100,000                | 8                             | 3                                 | 0.38                        | 15                      | 2.4                       | 2.4                           |
|         | 5     | 100,000                | 6                             | 1                                 | 0.33                        | 13                      | 3.5                       | 3.5                           |

\(^a\) The data are the results of separate UV exposure trials.

\(^b\) Total number for strong, moderate, and weak infections.

\(^c\) The level of inactivation was computed as follows: \(-\log(d/d_0)\), where \(d\) is the number of infectious cysts and \(d_0\) is the size of the inoculum.

\(^d\) The arithmetic mean level of inactivation was computed for each inoculum.
10,000 WB cysts. Strong and moderate infections, characterized by active trophozoites in the intestines and/or the presence of cysts in the feces, were also observed in gerbils inoculated with 20,000 WB isolate cysts exposed to a UV fluence of 0.5 mJ/cm² and in gerbils inoculated with 10,000 WB isolate cysts exposed to a UV fluence of 1 mJ/cm² (data not shown). This indicates that the isolate H3 cysts, although more infectious in the gerbils prior to UV exposure, were more readily inactivated by UV radiation.

Using the logistic dose-response models for isolates H3 and WB estimated in this study (Table 2), the level of inactivation of *G. lamblia* cysts was calculated for each of the four UV exposure experiments carried out with each isolate. The results are shown in Table 4. The total number of gerbils infected includes all infection levels (strong, moderate, and weak). The mean levels of inactivation at a UV fluence 40 mJ/cm² were calculated to be 2.0 log₁₀ for the WB isolate and 3.6 log₁₀ for the H3 isolate. The difference in the computed mean levels of UV inactivation between the two isolates was 1.6 log₁₀. Inactivation levels of the WB and H3 isolates were significantly different at the 95% confidence level (*P* = 0.03, as determined by a *t* test). The level of cyst inactivation determined in this study is compared to the level of UV inactivation of *G. lamblia* cysts determined in other studies in Table 5.

### DISCUSSION

In this study, the giardiasis infections in Mongolian gerbils were divided into three intensity categories based on the presence of cysts in the feces of inoculated gerbils and the presence and activity of trophozoites purified from the small intestine of gerbils. Weak infections characterized by the presence of only nonactive trophozoites in intestinal samples have not been reported by previous researchers who have carried out UV inactivation studies with *G. lamblia* using the Mongolian gerbil. Similar signs of weak infection were consistently absent in the uninoculated control gerbils. One hypothesis for the presence of the inactive trophozoites is that they originated from the original cyst inoculum and were not the result of trophozoite division within the host; that is, the parasites were able to excyst in the stomach of the gerbil, but the trophozoites that emerged from the cysts did not divide. A previous study showed that *G. muris* cysts that were exposed to UV irradiation were able to excyst but were not able to establish infections in mice (10). Given that the time between inoculation and examination of the intestines was 13 to 15 days and given the detection limit for trophozoites in the intestine by microscopy (approximately 10,000 trophozoites), it does not seem plausible that inactive trophozoites were detected in the intestinal samples without division occurring. Another hypothesis is that some of the cysts exposed to UV irradiation were able to repair their damaged DNA after ingestion by the host. Belosevic et al. (3) reported evidence of in vivo reactivation of *G. muris* in three of seven independent animal infectivity experiments when cysts were exposed to relatively low fluences of medium-pressure UV light (<25 mJ/cm²). Another recent study showed that *G. lamblia* cysts have the ability to repair their UV-damaged DNA after they are exposed to a UV fluence of 1 mJ/cm² from a low-pressure lamp (29). The problem with these arguments is that the weak infections were found not only in gerbils inoculated with UV-exposed cysts (Table 3) but also in gerbils inoculated with fresh cysts (Table 1).

In this study we directly compared two human isolates of *G. lamblia* cysts and their levels of inactivation by UV radiation. The results indicated that cysts of the two isolates, WB and H3, produced different levels of infections in the Mongolian gerbils both when fresh cysts were used and when cysts exposed to UV light were used. Isolate variation has been reported previously not only for infectivity in gerbils (31) but also for the clinical signs of giardiasis infections in humans (24). It should be noted that the Mongolian gerbil, although it is the preferred model not only for infectivity in gerbils (31) but also for the clinical signs of giardiasis infections in humans (24). The unique surface antigens could differentially protect the isolates from digestion by intestinal protease. Nash et al. (25) found that trophozoites of different isolates differ in the ability to survive after exposure to intestinal proteases, which implies that different isolates survive and

### TABLE 5. Summary of UV inactivation studies of *G. lamblia* cysts using the Mongolian gerbil model

| Isolate | Host age (wk) | Gender of host | Water matrix | Method used to estimate no. of viable cysts | UV dose (mJ/cm²) | Log_{10} reduction | Reference |
|---------|---------------|----------------|--------------|---------------------------------------------|-----------------|--------------------|-----------|
| WB      | NA            | NA             | Phosphate-buffered saline with 0.05% Tween 20 | ID₅₀            | 10              | <2                 | 7         |
| WB      | 4             | Female         | Filtered drinking water          | MPN            | 3               | ≥2                 | 22        |
| CH-3    | 8–10          | Female         | Buffered deionized water containing antibiotics | MPN            | 1               | >4                 | 19        |
| NA      | 8–10          | Female         | Buffered deionized water containing antibiotics | MPN            | 1               | ≥4                 | 29        |
| WB      | 4–8           | Male           | Deionized water                   | Logistic model  | 40              | 1.9                | This study |
| H3      | 4–8           | Male           | Deionized water                   | Logistic model  | 40              | 3.5                | This study |

*NA, not available.*
thrive to different degrees within the small intestine of the host. This may explain the number of low-intensity infections observed in the Mongolian gerbils inoculated with non-UV-exposed WB cysts. It is also possible that the H3 isolate cysts were better adapted to the gerbil host due to repeated passage, whereas the WB trophozoites were stored at −80°C and were passaged through the gerbils only once.

Table 5 shows that there are appreciable differences between the levels of UV inactivation reported in this study and the levels of UV inactivation reported in other studies in which the Mongolian gerbil was used as an infectivity model. The differences between studies may be related to a number of variables, including the methods used for cyst preparation and purification, the sex of the gerbils (male or female), the analytical methods and criteria used to define infection endpoints, and the mathematical methods used to interpret the infectivity results. UV inactivation of Giardia spp. may be influenced in part by the method used for cyst purification. The average level of inactivation of G. muris purified by an additional Percoll-sucrose flotation step was more than 1 log_{10} greater than the level of inactivation of G. muris purified by a single sucrose flotation step at a UV fluence of 40 mJ/cm², possibly due to a reduction in the residual fecal matter in the water matrix (2). In the present study, the same method (sucrose flotation) was used to purify both the WB and H3 isolate cysts.

In our study, male Mongolian gerbils were used as hosts, while other researchers have used female gerbils. There are distinct differences between male and female animals in terms of the ability to harbor and eliminate these intestinal parasites. The trophozoite burden was reported to be significantly higher in male mice infected with G. muris than in female mice (12). Infected male mice released cysts in their feces and harbored trophozoites in their intestines for a longer period than females. Therefore, giardiasis infections may be more readily detected in male gerbils than in females.

In this study, gerbils in which the only evidence of infection was the presence of nonactive trophozoites in intestinal samples were considered to be positive for infection. If these animals had been considered to be negative for infection, then no infections would have been scored for the UV-exposed isolate H3 cysts at all inoculum levels, and the reported level of inactivation would have been >4 log_{10}. This level of inactivation is more consistent with the findings of researchers who studied UV inactivation of CH-3 cysts (19, 29). Although these researchers indicated that infection was based on the presence of cysts in the feces or trophozoites in the intestine, they did not provide details concerning the intensity of the observed infections.

Both most-probable-number (MPN) and logistic model methods have been used to estimate the number of infectious cysts administered to gerbils. The MPN technique was originally developed to quantify bacteria using broth culture tubes and has been adapted for infectivity assays by some researchers (19, 22, 29). Even though animal models are recognized as the most appropriate method for testing the infectivity of Giardia spp. following UV exposure, the data generated with infectivity models vary considerably (28). The effect of variability in the animal response on the uncertainty in the MPN technique is unknown. Large differences (0.3 to 1.9 log_{10}) have been reported between direct hemocytometer counts of fresh cysts and the MPN estimated from infections in Mongolian gerbils (22). The number of infectious cysts may be significantly underestimated by the MPN method.

The levels of inactivation of the isolate WB and H3 cysts exposed to the same level of UV radiation using identical procedures and assessed using the same animal model were found to be considerably different. Even if the gerbils that were positive for nonactive trophozoites in the intestine were scored as negative, the level of inactivation of strain WB cysts was still limited to 2 log_{10} at a fluence of 40 mJ/cm². This difference between isolates may help explain apparent differences in levels of G. lamblia inactivation that have been observed in previous studies (Table 5). It has been reported previously that different isolates of Escherichia coli have different levels of UV sensitivity (30). In contrast, multiple isolates of C. parvum were found to be equally sensitive to UV disinfection (8, 27). This research provides the first evidence that different isolates of G. lamblia may not necessarily be equally sensitive to UV disinfection. Since the data set is still limited, more isolates of Giardia spp. need to be tested to support this hypothesis. In addition, it is not clear if the difference in sensitivity to UV radiation of these human-derived strains of G. lamblia is real or whether it is due to an artifact related to the Mongolian gerbil host model. Although the different isolates responded differently to UV when they were assessed using the Mongolian gerbil model, UV radiation appears to be very effective for inactivation of human G. lamblia isolates in water.

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