Review Article

Review of Non-ionized Electromagnetic Waves Effects on Human Parasites: A Systematic Review

Zahra Eslamirad[1], Homa Soleimani[2,3*]

ABSTRACT

So far, various natural and synthetic compounds have been used to treat and control parasites and their diseases, but now researchers have turned to mechanical and physical methods. This study aimed to review and categorize studies in which non-ionizing electromagnetic waves were used to control or treat human parasites. A systematic search was conducted. All English or full Persian articles on the investigation of electromagnetic waves on worms (Helminths) and protozoan parasites worldwide (from 1970 to 2023) indexed in Google Scholar, Science Direct, PubMed, Scopus, Medline, Medlib, Scientific Information Database, ProQuest, IranMedex, IranDoc, Embase and Magiran were collected and reviewed. Finally, 53 articles were included in the study. Its information was extracted and organized in tables based on the kind of non-ionizing wave.

The results of this study categorized the information obtained from the articles based on the type of non-ionizing waves and parasites. The findings of this study may serve as a guide for researchers as they create and execute future studies. This review study exposed the capability of non-ionizing electromagnetic waves to inactivate, control and treat parasitic diseases. This review revealed gaps in this field of study, and a road map was provided to design and implement new projects.

KEYWORDS: Electromagnetic radiations, Electromagnetic wave, Human, Health, Non-ionizing Irradiation, Parasitic diseases

INTRODUCTION

Parasitic diseases are a health problem in many developing and backward countries. So far, various methods have been tested to control and treat these diseases so that natural and synthetic chemical compounds are widely used[1,2]. Today, researchers consider using mechanical and physical techniques to prevent and treat parasitic diseases[3]. For example, the efficacy of microwave(MW) and infrared radiation in treating skin lesions caused by Leishmania major was investigated by Eskandari et al.[4]. Also, the effect of MW on protoscolices and Acanthamoeba was investigated by Eslamirad and Soleimani[5-8].

Electromagnetic waves have a relatively high ability to penetrate various tissues[9]. Because a wide range of these waves are non-ionized, they have less effect on natural cells[10]. The current review studied the results of studies in which different non-ionizing electromagnetic radiations were used to control and treat parasitic diseases. Collecting data about the effect of non-ionized electromagnetic radiation in preventing and treating parasitic infections in the last half century can be used in selecting the type of non-ionized electromagnetic waves, intensity, mode and radiation exposure time for future studies.

Search Process

All English or full Persian articles on the investigation of electromagnetic waves on worms (Helminths) and protozoan parasites worldwide (from 1970 to 2023) indexed in PubMed, Google Scholar, Science Direct, Scopus, Medline, Medlib, Scientific Information Database, IranMedex, IranDoc, Embase, ProQuest and Magiran were collected and reviewed. The keywords were a combination of Electrotherapy, Electromagnetic wave, Infrared Radiation, Infrared, Radiation, irradiation, rays, High-frequency electromagnetic field, Electromagnetic exposure, Electromagnetic Microwaves, Microwaves, Global System for Mobile (GSM) telephone, low-intensity radiofrequency fields, radiofrequency electromagnetic radiation, mobile wave, radiofrequency exposure, short-time microwave exposures, cell phone communication electromagnetic field, diathermy, shortwave therapy, ultraviolet, ultraviolet light, ultraviolet irradiation, photochemotherapeutic, worms, helminths, helminths parasite, nematoda, cestoda, trematoda, Fasciola, Dicrocoelium, Schistosoma, Echinococcus, hydatid disease, protoscolices, Taenia, Cysticercus, Hymenolepis, Protozoa, Protozoan parasite, Leishmania, Giardia, Entamoeba, microsporidium, Trichomonas, Acanthamoeba.

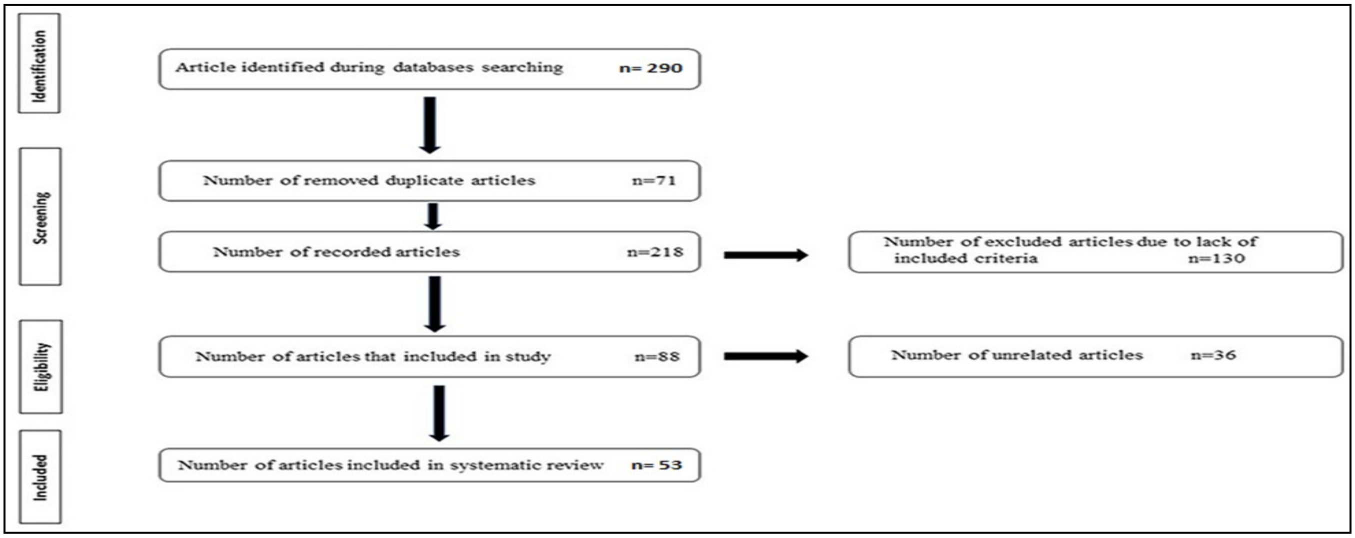
Selection strategy

The selection and approval of articles for the current systematic review are mentioned in **Figure I**.

[1]Department of Parasitology and Mycology, Arak University of Medical Sciences, Arak, Iran
[2]Department of Medical Physics, Faculty of Paramedicine, Arak University of Medical Sciences, Arak, Iran
[3]Department of Physiology, Medical School, Arak University of Medical Sciences, Arak, Iran
Correspondence: dr.hsoleimani@arakmu.ac.ir

doi: 10.22442/jlumhs.2024.001053
Received: 10-07-2023 Revised: 18-10-2023
Accepted: 24-10-2023 Published Online: 13-03-2024

Figure I: Step of selecting and approving articles for the current systematic review



The following criteria were considered in this study. Full English or Persian papers were published from 1970 to 2023, including non-ionizing electromagnetic waves that were used, from radiofrequency to ultraviolet (UV) waves. Moreover, selected articles were in the field of inactivation or treatment of human parasitic agents. In contrast, the papers that used magnetic field, electric field, ultra-sound, laser light, sunlight, case studies, and duplicate articles were excluded. **(Figure I)**

Data Extraction

Two researchers carefully reviewed selected papers and information, such as first author, year of publication, language, type of wave, intensity wave, time exposure, frequency, pulse mode, parasite, stage of the parasite, and mortality rate of parasite recorded.

BODY

The types of non-ionizing radiation and the number of articles included in the current study were ultraviolet (thirty-four articles), infrared (one), short wave (one), radio frequency (seven), microwaves (five) and mobile phone radiation (five).

Tables I and **II** show the characterization and summarization of the effect of non-ionizing waves on human parasites in the present study.

Table I-a: Summary of information on the effect of non-ionizing waves on protozoa

First Author (Year)	language	Type of Wave	Intensity, Frequency, Temperature	Time Exposure	Mode	Parasite	Stage of Parasite	Result	Type of study
Velasco-Castrejon (1997)[11]	En	RF	-, -,50˚C	30 s	Single-mode	*Leishmania*	Cutaneous Leishmaniasis (CL)	In 95% of patients, CL was completely cured	Treatment
Sadeghian (2007)[12]	En	RF	-	30s/week, 4 weeks	Pulse mode	*Leishmania*	CL	Heat therapy induced by RF was efficacious in the treatment of CL	Treatment
Wainwright (2009)[13]	En	RF	-, -, 50 to 70 ˚C	1 min	Continuous	*Toxoplasma*	Oocyst	The temperature produced by RF (up to 60 ° C and exposure time of 1 min) does not always inactivate *Toxoplasma* oocysts.	Experimental study (ES)
Aronson (2010)[14]	En	RF	-, -, 50˚C	30s	Single-mode	*Leishmania*	CL	The effect of the waves on the healing of leishmaniasis wounds was similar to that of sodium stibogluconate but with less toxicity.	Clinical trial
Eskandari (2012)[4]	En	RF (MW)	600 W, 2450 (GHz), -	0 to 12 min	Single-mode	*Leishmana*	CL	MW hampered the growth of lesions of leishmaniasis in mice.	Animal study
Sazgarnia (2013)[15]	En	RF (MW)	-, 2450 (MHz), -	0,6,12,24 and 40s	Single mode	*Leishmana*	Promastigote & amastigote	Mortality 100% in 40s	Medium culture & cell culture
Eslamirad (2020)[5]	Pe	RF (MW)	ΔT in maximum exposure time (Continuous mode 111 ˚ C; Repetitive mode 46.9 ˚ C)	Continuous mode (0 to 120s) & Repetitive mode (0 to 6×60 s)	Continuous & Repetitive	*Acanthamoeba*	Cyst	In both modes, the mortality rate of cysts was 100% in the maximum exposure time.	ES (in vitro)

Coronado (2023)[16]	En	MV	12 W, 2.45 (GHz), -	45 min	-	*Plasmodium*	-	MV can kill *Plasmodium* non-thermally	ES (in vitro)
Aksoy (2005)[17]	En	(Panasonic G-600, GSM 900 type)	-	60s/per 1hour/24 hour	-	*Entamoeba*	Trophozoite and cyst	The number of parasites exposed to mobile waves decreased	Medium culture (in vitro)
Cammaerts (2011)[18]	En	RF (Mobile)	2 W, 900 (MHz), 20 ˚ C	2 min	Repetitive mode	*Paramecium caudatum*	Trophozoite	The movement of irradiated parasites was slower than the control group.	ES
Sarapultseva (2011, 2014)[19,20]	En	RF (Mobile)	5& 50 μW/cm^2, 1 GHz. -	1 min to 10h	Continuous mode	*Spirostomum ambiguum*	Trophozoite	This wave was effective on the biology of this parasite	ES
Uskalova (2016)[21]	En	RF(Mobile)	50 μW/cm^2, 1 GHz, -	30, 60 & 360 min	-	*S.ambiguum*	Trophozoite	This kind of wave reduces the mobility of this	ES
Eskandarian (2012)[4]	En	IR (890 nanometers)	150 W	0 to 12 min	Single-mode	*Leishmania*	Amastigote	IR affected the growth of lesions of leishmaniasis in mice.	Animal study
Clancy (1998)[22]	En	UV	6× 85 W lamp (approximately 14.6 Mw·s/cm^2)	-	-	*Cryptosporidium parvum*	Oocyst	Pulsed UV and advanced UV inactivated *Cryptosporidium* oocysts	ES (in vitro and in vivo)
Clancy (2000)[23]	En	UV	low-pressure UV, 30 W (LP) and medium-pressure UV, 1Kw (MP) (approximately 14.6 Mw·s/cm^2)	-	-	*C.parvum*	Oocyst	Low dosages of UV can be highly effective for inactivating oocysts. However, the effect did not significantly differ.	ES (in vitro and in vivo)
Craik (2000)[24]	En	UV	1 Kw MP UV lamp,-, 20-22˚C	0 to 128 s	-	*Giardia muris*	Cyst	MP UV has the potential for inactivation of *Giardia* cyst.	ES (filtered drink water)

En: English; Pe: Persian
CL: Cutaneous leishmaniasis, ES: Experimental study
RF: Radiofrequency; MW: microwave; IR: infrared radiation; SWD: short wave diathermy; UV: Ultraviolet; LP: Low-pressure; MP: Medium pressure

Table I-b: Summary of information on the effect of non-ionizing waves on protozoa (continue)

First Author (Year)	Language	Type of Wave	Intensity, Frequency, Temperature	Time Exposure	Mode	Parasite	Stage of Parasite	Result	Type of study
Craik (2001)[25]	En	UV	Lp-10 W & Mp- 1 kW UV lamp, -, 4 ˚ C	0 to 168 s	-	*Cryptosporidium parvum*	Oocyst	Both LP & MP UV can be inactive the oocyst of this parasite in water	Experimental study (ES) (filtered drink water)
Linden (2002)[26]	En	UV	2×15 W lamp, -, 23-25° C	-	-	*Giardia lamblia*	Cyst	UV radiation can be used for disinfection of *G. lamblia* in water	ES
Morita (2002)[27]	En	UV	5 W	5 to 1000 s	-	*C. parvum*	Oocyst	Infectivity of cryptosporidium oocyst after UV irradiation decreased according to increased UV dose	ES
Campbell (2002)[28]	En	UV	-	60, 120 & 240 s	-	*G. lamblia*	Cyst	UV dose at 254nm resulted in significant inactivation of the Giardia cysts. Higher UV doses increased the inactivation of cysts.	ES (in vitro)
Maya (2003)[29]	En	UV	-	-	-	Amoeba *(Acanthamoeba)*	Trophozoite	The UV radiation can be inactivation *Acanthamoeba*	ES
Shin (2001)[30]	En	UV	15 W lamp	-	-	*C. parvum*	Oocyst	*C.parvum* oocysts are very sensitive to inactivation by low doses of UV, and there is no evidence of either light or dark repair of UV-induced DNA damage.	ES
Hayes (2003)[31]	En	UV	15 W	6 Hour	-	*G.muris*	Cyst	The UV radiation can inactivate *Giardia* cysts	ES
Zimmer (2003)[32]	En	UV	12 W LP & 1Kw MP, -, 5 or 25° C	-	-	*C. parvum*	Oocyst	Oocysts of *C.parvum* are very sensitive to inactivation by both UV, and there is no evidence of either light or dark repair of UV-induced DNA damage.	ES
Rochelle (2005)[33]	En	UV	-	-	-	*C. parvum*	Oocyst	The oocyst UV-induced DNA damage is repairable.	ES (in vitro and in vivo)
Johnson (2005)[34]	En	UV	-	-	-	*C.parvum and C. hominis*	Oocyst	The sensitivity of *C.hominis* to UV is similar to *C.parvum*	ES (in vitro and in vivo)
Amoah (2005)[35]	En	UV	1Kw MP UV	-	-	*Giardia & Cryptosporidium*	Cyst & oocyst	Water turbidity can result in reduced UV inactivation of cysts and oocysts.	ES (water with natural particulate matter)

Neto (2006)[36]	En	UV	-	-	-	*Giardia & Cryptosporidium (sludge treatment by UV radiation)*	Cyst & oocyst	Treatment of activated sludge with UV promoted the reduction of cysts and oocysts in sewage. However, the efficiency of inactivation of cysts of *Giardia* spp., post-UV treatment, in the field conditions was not complete.	ES (in vitro and in vivo)

En: English; Pe: Persian
CL: Cutaneous leishmaniasis; ES: Experimental study
RF: Radiofrequency; MW: microwave; IR: infrared radiation; SWD: short wave diathermy; UV: Ultraviolet; LP: Low-pressure; MP: Medium pressure

Table I-c: Summary of information on the effect of non-ionizing waves on protozoa (continue)

First Author (Year)	Language	Type of Wave	Intensity, Frequency, Temperature	Time Exposure	Mode	Parasite	Stage of Parasite	Result	Type of Study
Li (2007)[37]	En	UV	10 W	-	-	*Giardia lamblia* (WB and H3 isolate)	Cyst	Susceptibility of the two isolates of *Giardia* to UV light is different.	Experimental study (ES) in vitro and in vivo)
Van voorish (2003)[38]	En	UV	1 to 3 Jcm^{-2}	-	single	*Trypanosoma cruzi*	Trypomastigote	Amastigotes of *T. cruzi* sensitive to inactivation by amotosalen plus 3 Jcm^{-2} UV.	ES (in vitro)
Eastman (2005)[39]	En	UV	1 to 3 Jcm^{-2}		single	*Leishmania*	Metacyclic promastigotes and amastigotes	Metacyclic promastigotes and amastigotes were sensitive to inactivation by amotosalen plus 3 Jcm^{-2} UV.	ES (in vitro)
Grellier (2008)[40]	En	UV	1 to 3 Jcm^{-2}	-	single	*Babesia microti* and Plasmodium falciparum	Schizont	*P. falciparum* and *B. microti* were highly sensitive to inactivation by amotosalen and 1 Jcm^{-2} UV.	ES (in vitro)
Li (2008)[41]	En	UV	(1 to 100 $mJcm^{-2}$), -, 20±2 °C	30 s To 30 min	-	*Giardia lamblia*	Trophozoite	UV radiation may not eliminate the ability of the trophozoite stage of the parasites to reproduce in vitro at UV fluences up to 10$mJcm^{-2}$	ES (in vitro & in vivo)
Li (2009)[42]	En	UV	-	-	-	*Giardia lamblia*	Cyst	Using UV light as a disinfection method for wastewater provided less parasite inactivation than expected, based on the literature.	ES (in vitro and in vivo)
Shin (2009)[43]	En	UV	-	-	-	*Giardia lamblia*	Cyst	The inactivation of G. *lamblia* cysts was very rapid	ES
Weber (2009)[44]	En	UV	-	150 J/m^2	-	*Entamoeba histolytica*	Trophozoite	Ultraviolet light causes DNA damage in *E.histolytica,* and this damage is effective in expressing some of the genes of this parasite.	ES (in vitro)
Santos (2013)[45]	En	UV	High-intensity UV	-	-	*Giardia duodenalis*	Trophozoite & cyst	*G. duodenalis* cysts exposed to UV light were damaged but were still able to cause Infection.	ES
Cervero-Aragó (2014)[46]	En	UV	-	-	-	*Vermamoeba & Acanthamoeba*	Trophozoite & cyst	The UV effect on this parasite's trophozoite is higher than that of cysts.	ES (in vitro)
Mayelifar (2015)[47]	En	UV	3×20 W lamp (135 $\mu W/cm^2$)	148, 222 & 370s	-	*Leishmania*	Lesion on CL in mice	It could be suggested that UV (B) in the presence of Ag Nanoparticles, by inhibiting the spread of CL lesions and reducing the rate of visceral progression of the disease, provides an antileishmanial effect.	ES (in vivo, animal study)
Einarsson (2015)[48]	En	UV	-	20 s	-	*Giardia intestinalis*	Trophozoite & cyst	UV radiation at 10 mJ/cm2 kills *Giardia* cysts effectively, whereas trophozoites and encysting parasites can recover from UV treatment at 100 mJ/cm2 and 50 mJ/cm2, respectively. Also, UV radiation induces small overall changes in gene expression in *Giardia,* but cysts show a stronger response than trophozoites.	ES (water waste)
Adeyemo (2019)[49]	En	UV	10 W,-,20±2 °C	0, 10,20,40,80 & 160s	-	*Giardia, Cryptosporidium*	Cyst & oocyst	The UV radiation inactivated the cyst of *Giardia* and the oocyst of *Cryptosporidium* in wastewater, but the oocyst responded to a higher UV dose.	ES (water waste)

En: English; Pe: Persian
CL: Cutaneous leishmaniasis; ES: Experimental study
RF: Radiofrequency; MW: microwave; IR: infrared radiation; SWD: short wave diathermy; UV: Ultraviolet; LP: Low-pressure; MP: Medium pressure

Table II: Summary of information on the effect of non-ionizing waves on worms

First Author (Year)	Language	Type of Wave	Intensity of Wave, Frequency, Temperature	Time Exposure	Mode	Parasite	Stage of Parasite	Results	Type of study
Brunetti (2001)[50]	En	RF	100 (P), 480 (kHz), -	8 min	-	*Echinococcus*	Liver cyst	No protoscolices and residual of the germinal layer were found	Treatment
Zacharoulis (2006)[51]	En	RF	-, 500 (kHz), -	-	Manual mode	*Echinococcus*	Liver cyst	This method was effective	Treatment (RF- assisted pericystectomy)
Botsa (2017)[52]	En	RF	90-110 W, -, -	10 min	Pulse mode	*Echinococcus multilocularis*	Liver cyst	The liver cyst was successfully treated	Treatment
Eslamirad (2015)[7]	En	RF (MW)	1550 W, 2450 (MHz), -	Continuous (0, 15, 20, 25, 30, 35, 40, 45, 50 s) & Repetitive (0, 4, 6, 8,10,16,18,20s × 10)	Continuous & Repetitive	*Echinococcus*	Protoscolices	In both modes, the mortality rate of protoscolices was 100% in the maximum exposure time.	Experimental study (ES) (in vitro)
Soleimani (2020)[8]	En	RF (Mobile)	< 1 W, 3 GHz, ΔT was variable	0 to 2000 s	Repetitive mode	*Echinococcus*	Protoscolices	The mortality rate of protoscolices was directly proportional to the time of exposure and inversely proportional to the distance from the mobile generation waves.	ES
Eslamirad (2020)[6]	En	RF (Short Wave Diathermy, SWD)	350 & 450 W, -, -	0, 0.5, 1 & 2 min	Continuous mode	*Echinococcus*	Protoscolices	Time exposure and machines' power could affect protoscolices' mortality rate.	ES
Herlich (1980)[53]	En	UV	100 to 500 μW-min/cm^2, -, 25 ˚ C	-	-	Ostertagia ostertagi, Trichostrongylus axei, and Tricho-strongylus colubriformis,	Infective larva (L3)	Number of worms that were recovered in experimental animals was sharply reduced at 200 or more doses of UV	ES
Ariyo (1990)[54]	En	UV	-	1,3,5,10 & 20 s	-	*Schistosoma mansoni*	Cercaria	Cercaria activity decreased with increasing dose levels of UV radiation. Also, cercaria's Maturation and penetration rates depended on radiation exposure levels.	ES (in vitro)
Ruelas (2007)[55]	En	UV	-	0,1,3,7, 14 day	-	*Schistosoma mansoni*	Miraidium & sporocyst	Irradiation of miracidia with UVB resulted in decreased prevalence of patent infection in a dose-dependent manner	ES
Dehghani (2012)[56]	En	UV	11W (24 μW/ cm^2), -, -	1 to 10 min	-	Free nematoda (Rhabditida)	Larva and adult worm	The UV radiation can have inactivated larvae and adult worms at 9 and 10 minutes, respectively.	ES (in vitro)
Studer (2012)[57]	En	UV	80W, -, -	-	-	Trematoda	Cercaria	Survival of cercariae decreased strongly in a dose-dependent manner, while susceptibility of amphipods increased after exposure to UVR for a prolonged period. Exposure to UVR thus negatively affects both the parasite and its amphipod host.	ES
Kent (2019)[58]	En	UV	-	-	-	*Pseudocapillaria tomentosa*	Eggs	*UV rays reduced the formation of larvae from the eggs of this parasite.*	ES

En: English; Pe: Persian
RF: Radiofrequency; MW: microwave; ES: Experimental study
IR: infrared radiation; SWD: short wave diathermy; UV: Ultraviolet;

DISCUSSION

Since the early twentieth century, drug resistance and its side effects have become a big challenge for drug development. For this reason, the use of radiation to inactivate various microorganisms (including viruses, bacteria, and parasites) has received more attention[59]. X-rays were the first kind of radiation utilized to inactivate a parasitic organism in this century, and additional electromagnetic waves were progressively introduced to inactivate parasites in the environment, culture medium, and host body over different decades (in vivo)[60,61].

Effect of non-ionization radiation on parasites

Effect of radiofrequency electromagnetic field on protozoa

The studies showed the effectiveness of *radiofrequency* radiation on protozoa even in short time exposure (<1 min) in the single or continuous mode. So, our research indicated RF could destroy *Acanthamoeba,* which has dormant and highly resistant cysts[8]. However, a few articles about RF's therapeutic effect on protozoa were published; 5 (45%) of the 11 published manuscripts were about *Leishmana*. There were two articles related to *Spirostomum ambiguum*. A published article was found for each protozoan: *Acanthamoeba, Entamoeba, Paramecium caudatum, Plasmodium* and *Toxoplasma* (**Table II**).

The temperature of the RF exposure environment was not determined in all of these studies. Still, some researchers showed that RF radiation leads to parasite death or reduced parasite activity with thermal effects. The RF thermal effect has been investigated for cases such as treatment of cutaneous leishmaniosis (50°C, 30s) in laboratory animals, inactivation of *Toxoplasma* oocysts (50-70 °C, 1min) in water and treatment of hepatic hydatid cysts in humans.

Since 2011, studies have been conducted on the effect of RF waves on parasites in the mobile phone frequency range (**Table I & II**). These researchers indicated microwaves increase the mortality of *Acanthamoeba* cysts[8]. Evaluating the effect of microwaves in two continuous and repetitive modes on larvae of *Echinococcus* (protoscolices) also showed that these waves lead to an increase in protoscolices mortality, which was dependent on the duration of radiation[7]. Evaluating the potential of cyst formation of irradiated microwave protoscolices confirmed that the cystogenesis ability of irradiated protoscolices decreased compared to the control group in vivo (laboratory animal). Still, this difference was not statistically significant[62]. These effects were evident even in short-term exposure. The time of exposure and distance from the RF source (mobile phone) were two factors that contributed to the mortality rate[8].

The results of a study showed that infrared radiation (IR) is effective in the growth of lesions caused by *Leishmania major* (12min). So, its effect in inhibiting the growth of lesions in mice is greater than that of radiofrequency[4].

Effect of UV rays on protozoa

Evaluation of research conducted on the effect of UV rays on parasites showed that most studies were designed and implemented to control waterborne protozoa, especially *Giardi*a and *Cryptosporidium*. These studies were performed in vitro and in vitro, and a limited number of them were tested in watersheds, water resources, and sewage systems[22-28,30-37,41-43,45,48,49].

Furthermore, researchers suggested that UV waves could be used as an alternative to chemicals to disinfect and control waterborne parasites[24,25,63]. Also, UV radiation in the presence of other compounds, such as riboflavin, can affect the parasite[64]. On the other hand, several researchers found that UV radiation induces an arrest to DNA replication in *Cryptosporidium* and *Giardia trophozoites*, and cysts derived from these irradiated trophozoites are incapable of repairing the damage caused by UV radiation[32]. The effect of UV radiation on other parasites, such as amoebae (including *Acanthamoeba* and *Vermameoba*), was investigated. The results confirmed the impact of UV radiation on parasite activity gene expression and causing DNA damage[29,46].

Research has shown that UV radiation is a suitable method to eliminate or reduce the protozoa in surface soil and water environments such as sewage. The ability to pass UV waves depends on the transparency of water or any other solution. Water turbidity could result in reduced UV inactivation of cysts and oocyst[35]. The researchers also studied the effects of temperature and intensity on the UV dose requirement. The results showed that for every 10°C decrease in water temperature, an increase in the dose of UV radiation (10-fold increase in intensity) was required for a 2-log10 reduction in infectivity of the protozoa[27].

On the other hand, studying the synergistic effect of UV radiation with silver nanoparticles in the healing of cutaneous *Leishmania* lesions in mice showed that UV rays increase the anti-Leishmania properties of silver nanoparticles[65]. Data concerning the role of UV suggest a possible use of a combined method on parasites to reduce the dose of drugs and the side effects of drugs[38,39,66].

Effects of UV light on worm

The efficacy of UV light on worm parasites was studied. UV radiation effects were assessed on the life cycle and the maturity rate of some parasitic trematodes and nematode larvae. Hence, infectious larvae of this group of worms were exposed to UV radiation, and then the number of adult worms resulting from these larvae was examined. These studies confirmed that UV radiation affects the development of larvae and reduces the number of adult worms (53-58). These effects depended on UV's type, level, and fluency.

Effects of radiofrequency electromagnetic field on worm

Limited studies were performed on the effect of other non-ionizing waves in the RF spectrum, including micro (100 kHz-3GHz) and infrared radiation (IR) waves. The results of studies on the effect of microwaves on *Leishmania* showed that these waves lead to the death of the Leishmania parasite in culture medium (both cellular and non-cellular) and can reduce the size of lesions caused by this parasite in laboratory animals[4,14,15].

In addition to investigating the effect of microwaves on pathogenic parasites, these waves were used to control soil nematodes, and their impact on reducing the number of this type of worm in the soil was confirmed[67,68].

The effect of mobile waves on mortality and the number of parasites such as *Entamoeba*[16], *Paramecium*[18], *Spirostomum*[19-21] and larvae of *Echinococcus*[8] were evaluated, and the effect of these waves was confirmed. Moreover, some of these studies investigated the duration of radiation, the kind of wave, and the distance of the parasite agent from the radiation source[8,16,17].

This review study exposed the research gaps in determining the capability of electromagnetic waves to inactivate, control and treat parasitic diseases. In other words, the results of this study can help researchers as a roadmap for designing and performing a new research plane of non-ionization against dangerous ionizing rays. In addition, it was found that the characteristics of non-ionizing rays (such as radiation mode, power, time exposure and temperature changes) were not announced in a high percentage of articles (Tables I & II). Since any change in the mentioned factors leads to specific results, these are recommended for future studies.

CONCLUSION

According to the results of all the above-discussed studies, it can be concluded that all non-ionizing waves which were studied on some human parasites have had a negative impact on different life stages of these parasites (the number of eggs or cysts, reproductive stages, and infectivity, etc.). These effects depended on the wave, radiation mode and parasite-type characteristics. Also, considering few studies in this field, there is a need for more research on the effects of IR and especially RF radiation on human parasites. On the other hand, it seems that the waves in the mobile phone range produce less heat. So, considering that these electromagnetic waves have a shorter wavelength and a fast oscillation rate and quickly penetrate the body, it may be possible to benefit from using non-thermal effects to affect parasites in vitro (human body) negatively.

Ethical Permission: Arak University of Medical Sciences, Iran, REC letter No. 059 IR.ARAKMU. REC.1402.

Conflict of Interest: The authors have no conflict of interest to declare

Financial Disclosure / Grant Approval: This research did not receive specific funding from any financially supporting body.

Data Sharing Statement: The corresponding author can provide the data proving the findings of this study on request. Privacy or ethical restrictions bound us from sharing the data publically.

AUTHOR CONTRIBUTION

All authors participated in writing an original draft, conceptualizing the study, and supervising the article. All authors reviewed and approved the final version of the manuscript.

REFERENCES

1. Kerboeuf D, Riou M, Guegnard FG. Flavonoids and related compounds in parasitic disease control. Mini Rev Med Chem. 2008; 8(2): 116-28. doi: 10.2174/138955708783498168.
2. Fenwick A, Savioli L, Engels D, Robert Bergquist N, Todd MH. Drugs for the control of parasitic diseases: current status and development in schistosomiasis. Trends Parasitol. 2003; 19(11): 509-15. doi: 10.1016/j.pt.2003.09.005.
3. Ozlim Caliskan S, Ertabaklar H, Dincer Bilgin M, Ertug S. Assessment of the Effects of Extremely Low-Frequency Electromagnetic Fields on Toxoplasma Gondii. Iran J Parasitol. 2016; 11(2): 159-167.
4. Eskandari S, Azimzadeh A, Bahar M, Safai Naraghi Z, Javadi A, Khamesipour A et al. Efficacy of Microwave and Infrared Radiation in the Treatment of the Skin Lesions Caused by Leishmania Major in an Animal Model. Iran J Public Health. 2012; 41(8): 80-83.
5. Eslamirad Z, Haji Hajihossein R, Soleimani H. Evaluating Potential of Electromagnetic Microwaves on Destruction Acanthamoeba Cysts. CMJA. 2020; 9(4): 3868-77.
6. Eslamirad Z, Hajihossein R, Soleimani H. Is Shortwave Diathermy Effective on Mortality of Protoscolices? Open Access Macedon J Med Sci. 2020; 8(A): 55-8. doi: 10.3889/oamjms. 2020. 3816.
7. Eslamirad Z, Soleimani H, Hajihossein R, Rafiei F. Evaluation of lethal effect of microwave exposure on protoscolices of hydatid cyst in vitro. Asian Pac J Trop Dis. 2015; 5(10): 821-4. doi: 10.1016/522222-1808(15)60938-0.
8. Soleimani H, Hajihossein R, Eslamirad Z. Mobile

Phone Radiation: Its Efficacy as Protoscolicidals. Turkiye Parazitol Derg. 2020; 44(4): 203-206. doi: 10.4274/tpd.galenos. 2020.6722.
9. Alonzo M, Bos A, Bennett S, Ferral H. The Emprint™ Ablation System with Thermosphere™ Technology: One of the Newer Next-Generation Microwave Ablation Technologies. Semin Intervent Radiol. 2015; 32(4): 335-8. doi: 10.1055/ s-0035-1564811.
10. Harid V, Kim H, Li BZ, Lei T. A method for non-destructive microwave focusing for deep brain and tissue stimulation. PLoS One. 2023; 18(2): e0278765. doi: 10.1371/journal.pone. 0278765.
11. Velasco-Castrejon O, Walton B, Rivas B, Garcia M, Lazaro G, Hobart O et al. Treatment of Cutaneous Leishmaniasis with Localized Current Field (Radio Frequency) in Tabasco, Mexico. Am J Trop Med Hyg. 1997; 57: 309-12. doi: 10.4269/ ajtmh.1997.57.309.
12. Sadeghian G, Nilfroushzadeh MA, Iraji F. Efficacy of local heat therapy by radiofrequency in the treatment of cutaneous leishmaniasis, compared with intralesional injection of meglumine antimoniate. Clin Exp Dermatol. 2007; 32(4): 371-4. doi: 10.1111/j.1365-2230.2007.02405.x. Epub 2007 Mar 21.
13. Wainwright K, Lagunas-Solar M, Miller M, Barr B, Melli A, Packham A et al. Radiofrequency-Induced Thermal Inactivation of Toxoplasma gondii Oocysts in Water. Zoonoses Public Health. 2009; 57: 74-81. doi: 10.1111/j.1863-2378.2009. 01280.x. Epub 2009 Sep 10.
14. Aronson NE, Wortmann GW, Byrne WR, Howard RS, Bernstein WB, Marovich MA et al. A Randomized Controlled Trial of Local Heat Therapy Versus Intravenous Sodium Stibogluconate for the Treatment of Cutaneous Leishmania major Infection. PLOS Neglected Tropical Diseases. 2010; 4(3): e628.
15. Sazgarnia A, Taheri AR, Soudmand S, Jafari Parizi A, Rajabi O, Sadat Darbandi M. Antiparasitic effects of gold nanoparticles with microwave radiation on promastigotes and amastigotes of Leishmania major. Int J Hyperthermia. 2013; 29(1): 79-86.
16. Coronado LM, Stoute JA, Nadovich CT, Cheng J, Correa R, Chaw K et al. Microwaves can kill malaria parasites non-thermally. Front. Cell. Infect. Microbiol. 2023: 13: 955134.
17. Aksoy U, Sahin S, Ozkoc S, Ergor G. The effect of electromagnetic waves on the growth of Entamoeba histolytica and Entamoeba dispar. 2005; 26(9): 1388-90.
18. Cammaerts M-C, Debeir O, Cammaerts R. Changes in Paramecium caudatum (Protozoa) near a switched-on GSM telephone. Electromagn Biol Med. 2011; 30(1): 57-66.
19. Sarapultseva EI, Igolkina JV. Experimental Study of Relationship between Biological Hazards of Low-Dose Radiofrequency Exposure and Energy Flow Density in Spirostomum Ambiguum Infusoria Exposed at a Mobile Connection Frequency (1 GHz). Bull Exp Biol Med.. 2011; 151(4): 477-480. doi: 10.1007/s10517-011-1361-5.
20. Sarapultseva EI, Igolkina JV, Tikhonov VN, Dubrova YE. The in vivo effects of low-intensity radiofrequency fields on the motor activity of protozoa. Int J Radiat Biol. 2014; 90(3): 262-7.
21. Uskalova DV, Igolkina YV, Sarapultseva EI. Intravital Computer Morphometry on Protozoa: A Method for Monitoring of the Morphofunctional Disorders in Cells Exposed in the Cell Phone Communication Electromagnetic Field. Bull Exp Biol Med. 2016; 161(4): 554-7.
22. Clancy JL, Hargy TM, Marshall MM, Dyksen JE. UV light inactivation of Cryptosporidium oocysts. Journal AWWA. 1998; 90(9): 92-102.
23. Clancy JL, Bukhari Z, Hargy TM, Bolton JR, Dussert BW, Marshall MM. Using UV to inactivate Cryptosporidium. Journal AWWA. 2000; 92(9): 97-104.
24. Craik SA, Finch GR, Bolton JR, Belosevic M. Inactivation of Giardia muris cysts using medium-pressure ultraviolet radiation in filtered drinking water. Water Res. 2000; 34(18): 4325-32.
25. Craik SA, Weldon D, Finch GR, Bolton JR, Belosevic M. Inactivation of cryptosporidium parvum oocysts using medium- and low-pressure ultraviolet radiation. Water Res. 2001; 35(6): 1387-98.
26. Linden KG, Shin G-A, Faubert G, Cairns W, Sobsey MD. UV Disinfection of Giardia lamblia Cysts in Water. Environ Sci Technol Lett. 2002; 36(11): 2519-22.
27. Morita S, Namikoshi A, Hirata T, Oguma K, Katayama H, Ohgaki S et al. Efficacy of UV irradiation in inactivating Cryptosporidium parvum oocysts. Appl Environ Microbiol. 2002; 68(11): 5387-93.
28. Campbell AT, Wallis P. The effect of UV irradiation on human-derived Giardia lamblia cysts. Water Res. 2002; 36(4): 963-9.
29. Maya C, Beltrán N, Jiménez B, Bonilla P. Evaluation of the UV disinfection process in bacteria and amphizoic amoebae inactivation. Water Supply. 2003; 3(4): 285-91.
30. Shin G, Linden K, Arrowood M, Sobsey M. Low-pressure UV inactivation and DNA repair potential of Cryptosporidium parvum oocysts. Appl Environ Microbiol. 2001; 67(7): 3029-32.
31. Hayes SL, Rice EW, Ware MW, Schaefer FW. Low-pressure ultraviolet studies for inactivation of Giardia muris cysts. J Appl Microbiol. 2003; 94(1): 54-9.
32. Zimmer JL, Slawson RM, Huck PM. Inactivation and potential repair of Cryptosporidium parvum

following low- and medium-pressure ultraviolet irradiation. Water Res. 2003; 37(14): 3517-23.
33. Rochelle PA, Upton SJ, Montelone BA, Woods K. The response of Cryptosporidium parvum to UV light. Trends Parasitol. 2005; 21(2): 81-7.
34. Johnson AM, Linden K, Ciociola KM, De Leon R, Widmer G, Rochelle PA. UV Inactivation of Cryptosporidium hominis as Measured in Cell Culture. Appl Environ Microbiol. 2005;71(5):2800-2.
35. Amoah K, Craik S, Smith DW, Belosevic M. Inactivation of Cryptosporidium oocysts and Giardia cysts by ultraviolet light in the presence of natural particulate matter. J WATER SUPPLY RES T. 2005; 54(3): 165-78.
36. Neto RC, Santos JU, Franco RMB. Evaluation of activated sludge treatment and the efficiency of the disinfection of Giardia species cysts and Cryptosporidium oocysts by UV at a sludge treatment plant in Campinas, south-east Brazil. Water Sci Technol. 2006; 54(3): 89-94.
37. Li D, Craik SA, Smith DW, Belosevic M. Comparison of levels of inactivation of two isolates of Giardia lamblia cysts by UV light. Appl Environ Microbiol. 2007; 73(7): 2218-23.
38. Van Voorhis WC, Barrett LK, Eastman RT, Alfonso R, Dupuis K. Trypanosoma cruzi inactivation in human platelet concentrates and plasma by a psoralen (amotosalen HCl) and long-wavelength UV. Antimicrob Agents Chemother. 2003; 47(2): 475-9.
39. Eastman RT, Barrett LK, Dupuis K, Buckner FS, Van Voorhis WC. Leishmania inactivation in human pheresis platelets by a psoralen (amotosalen HCl) and long□wavelength ultraviolet irradiation. Transfusion. 2005; 45(9): 1459-63.
40. Grellier P, Benach J, Labaied M, Charneau S, Gil H, Monsalve G et al. Photochemical inactivation with amotosalen and long-wavelength ultraviolet light of Plasmodium and Babesia in platelet and plasma components. Transfusion. 2008; 48(8): 1676-84.
41. Li D, Craik SA, Smith DW, Belosevic M. Survival of Giardia lamblia trophozoites after exposure to UV light. FEMS Microbiology Letters. 2008; 278 (1): 56-61.
42. Li D, Craik SA, Smith DW, Belosevic M. Infectivity of Giardia lamblia cysts obtained from wastewater treated with ultraviolet light. Water Res. 2009; 43 (12): 3037-46.
43. Shin G-A, Linden KG, Faubert G. Inactivation of Giardia lamblia cysts by polychromatic UV. Lett Appl Microbiol. 2009; 48(6): 790-2.
44. Weber C, Marchat LA, Guillen N, López-Camarillo C. Effects of DNA damage induced by UV irradiation on gene expression in the protozoan parasite Entamoeba histolytica. Mol Biochem Parasitol. 2009; 164(2): 165-9.
45. Santos LUd, Alves DP, Guaraldo AMA, Cantusio Neto R, Durigan M, Franco RMB. Infectivity of Giardia duodenalis Cysts from UV Light-Disinfected Wastewater Effluent Using a Nude BALB/c Mouse Model. ISRN Parasitology. 2013; 2013: 713958.
46. Cervero-Aragó S, Sommer R, Araujo RM. Effect of UV irradiation (253.7 nm) on free Legionella and Legionella associated with its amoebae hosts. Water Res. 2014; 67: 299-309.
47. Mayelifar K, Taheri A, Rajabi O, Sazgarnia A. Ultraviolet B Efficacy in Improving Anti-leishmanial Effects of Silver Nanoparticles. Iran J Basic Med Sci. 2015; 18(7): 677-683.
48. Einarsson E, Svärd S, Troell K. UV irradiation responses in Giardia intestinalis. Exp Parasitol. 2015; 154: 25-32. doi: 10.1016/j.exppara.2015.03.024. Epub 2015 Mar 28.
49. Adeyemo FE, Singh G, Reddy P, Bux F, Stenström TA. Efficiency of chlorine and UV in the inactivation of Cryptosporidium and Giardia in wastewater. PLoS ONE. 2019; 14: e0216040.
50. Brunetti E, Filice C. Radiofrequency thermal ablation of echinococcal liver cysts. Lancet. 2001; 358(9291): 1464. doi: 10.1016/S0140-6736(01)06518-7.
51. Zacharoulis D, Poultsidis A, Roundas C, Tepetes K, Hatzitheofilou C. Liver Hydatid Disease: Radiofrequency-Assisted Pericystectomy. Ann R Coll Surg Engl. 2006; 88: 499-500.
52. Botsa E, Thanou I, Nikas I, Thanos L. Treatment of Hepatic Hydatid Cyst in a 7-Year-Old Boy Using a New Type of Radiofrequency Ablation Electrode. Am J Med Case Rep. 2017; 18: 953-8.
53. Herlich H, Tromba F. Effect of Ultraviolet Radiation on Some Gastrointestinal Nematode Parasites of Cattle. J Parasitol. 1980; 66(4):692-4.
54. Ariyo AA, Oyerinde JP. Effect of ultraviolet radiation on survival, infectivity and maturation of Schistosoma mansoni cercariae. Int J Parasitol. 1990; 20(7): 893-7.
55. Ruelas DS, Karentz D, Sullivan JT. Sublethal Effects of Ultraviolet B Radiation on Miracidia and Sporocysts of Schistosoma mansoni: Intramolluscan Development, Infectivity, and Photoreactivation. J Parasitol. 2007; 93(6): 1303-10.
56. Dehghani M, Zarei A, Mahvi A, Jahed G, Kia E. Investigating the Efficiency of Ultraviolet Irradiation for Inactivation of Free-Living Nematodes in Water.[In Farsi]. Iran J Health Environ. 2012; 4(4): 219-225.
57. Studer A, Lamare M, Poulin R. Effects of ultraviolet radiation on the transmission process of an intertidal trematode parasite. Parasitology. 2012; 139: 537-46.
58. Kent ML, Watral V, Villegas EN, Gaulke CA. Viability of Pseudocapillaria tomentosa Eggs Exposed to Heat, Ultraviolet Light, Chlorine,

Iodine, and Desiccation. Zebrafish. 2019; 16(5): 460-8.
59. Pole JC. Quarzlampen für ultraviolettes Licht in der Praxis. In: Pole JC, editor. Die Quarzlampe: ihre Entwicklung und ihr heutiger Stand. Berlin, Heidelberg: Springer Berlin Heidelberg; 1914. p. 74-84.
60. Tyzzer EE, Honeij JA. The Effects of Radiation on the Development of Trichinella Spiralis, with Respect to Its Application to the Treatment of Other Parasitic Diseases. J Parasitol. 1916; 3(2): 43-56.
61. Lloyd JJ. Ultraviolet Radiation in Medicine. In: Webster JG, editor. Encyclopedia of Medical Devices and Instrumentation. Second ed: John Wiley & Sons, Inc.; 2006. p. 473-90.
62. Eslamirad Z, Soleimani H. Investigating the Potential of Protoscolices for Cyst Formation under in vivo Microwave Radiation. CMJA. 2019; 9(1): 3598-606.
63. Hijnen WAM, Beerendonk EF, Medema GJ. Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo)cysts in water: A review. Water Res. 2006; 40(1): 3-22.
64. Owusu-Ofori S, Kusi J, Owusu-Ofori A, Freimanis G, Olver C, Martinez CR et al. Treatment of Whole Blood With Riboflavin and UV Light: Impact on Malaria Parasite Viability and Whole Blood Storage. Shock. 2015; 44(Suppl 1): 33-8.
65. Mayelifar K, Sazgarnia A, Yadegari Dehkordi S, Eshghi H, Attaran N, Soudmand Salarabadi S. Inhibitory Effect of Electroporation and Silver Nanoparticles on the Growth of Leishmania major Promastigotes Influence of Pulse Duration. Med J Mashhad Univ Med Sci. 2013; 56(4): 247-254.
66. Lanteri MC, Santa-Maria F, Laughhunn A, Girard YA, Picard-Maureau M, Payrat JM et al. Inactivation of a broad spectrum of viruses and parasites by photochemical treatment of plasma and platelets using amotosalen and ultraviolet A light. Transfusion. 2020; 60(6): 1319-31.
67. O'Bannon JH, Good JM. Applications of microwave energy to control nematodes in soil. Journal of nematology. 1971; 3(1): 93-4.
68. Rahi G, Rich J. Potential of Microwaves to Control Plant-Parasitic Nematodes in Soil. J microw power electromagn energy. 2008; 42: 5-12.