Effect of germicidal UV-C light on Viruses, Bacteria, other Microorganisms and Dust Mites

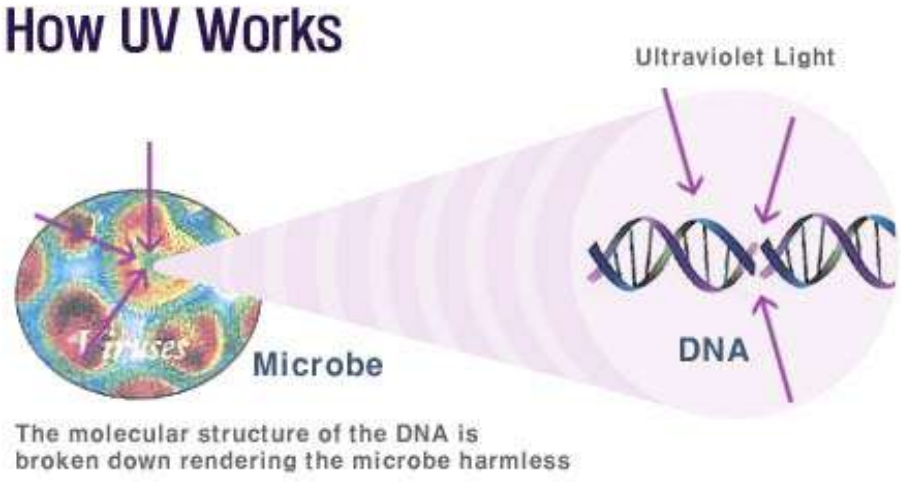
UVC MAX

Micro-organisms are microscopically small. They are everywhere around us and have an extremely high metabolism. For example, in hot and humid weather the amount of mold spores, dust mites and bacteria increases exponentially.

Furthermore, micro-organisms produce mucus substances that are deposited and contaminate various surfaces around us, mattresses included.

The role of UV-C

In 1878, Arthur Downes and Thomas P. Blunt published a paper describing the sterilization of bacteria exposed to short-wavelength light. UV has been a known mutagen at the cellular level for over 100 years. The 1903 Nobel Prize for Medicine was awarded to Niels Finsen for his use of UV against lupus vulgaris, tuberculosis of the skin.
UV light is electromagnetic radiation, containing 265-nm wavelengths, UV is capable of inducing mutation to bacteria, viruses, and other microorganisms due to its effects on the molecular structures of the pathogens. Its action results in destroying the structural bonds in the DNA of the pathogens, with a resultant rendering of the pathogens harmless or thereby inducing a bacteriostatic action on the pathogens.
UV light is able to sever the molecular bonds in DNA and RNA when used at specific wavelengths, thereby destroying micro-organisms. They are particularly vulnerable to UV light at 254 nm because DNA absorbs UV light maximally in this region, resulting in the formation of lethal photoproducts.
The cell nucleus of micro-organisms contains thymine, a chemical element of the DNA / RNA. This element absorbs UV-C light at a specific wavelength of 253.7 nm and changes to such an extent (formation of thymine dimers) that the cell is no longer capable of multiplying and surviving.



UV-C light causes damage to the nucleid acid of microorganisms by forming covalent bounds between certain adjacent bases in the DNA. The formation of such bonds prevent the DNA from being unzipped for replication and the organism is unable to reproduce. In fact when the organism try to replicate it dies.

UV-C light disinfection system deliver doses

UV-C light disinfection systems deliver doses of UV light at 254 nm, as a variety of microorganisms including spore-forming bacteria are vulnerable to UV light at this wavelength; however, the doses needed to inactivate them can vary between species. In the **Appendix A** you can find the exact UV Rate Constants for Bacteria, Viruses , Fungi and Other Microbes.
UV-C light is able to inactivate microorganisms on surfaces, in air and in water.
The disinfection surfaces is perhaps the simplest and most predictable application of ultraviolet germicidal radiation.
UV is highly effective at controlling microbial growth and at achieving sterilization of most types of surfaces. Our machine Germinator 1 specialized unit for mattress and pillows disinfection is using Low Pressure Germicidal Ultraviolet lamps produces by First Light Technologies, Inc (Poultney, Vermont ,USA) the leading manufacturer of low pressure UVC lamp in both the 185 and 254 nm wavelengths. Many bad bacteria can be found on the mattresses that are public used especially mattresses in the hospitals. The study that you can find in the **source 1** is showing some of the bacteria's that were found on the mattresses.

Surface disinfection as a practice

Among others UV is an effective nonthermal intervention method for surface decontamination of bactreia like E. coli O157:H7 and L. monocytogenes on fresh produce and packaging materials. **(Source 2)**

Scientific studies conclude that common pathogens and microorganisms may well survive or persist on surfaces for 24 hours to months (depending on the type), and can thereby be a continuous source of transmission if no regular preventive surface disinfection is performed **(Source 3,4)**

More information on how and why UV is used against bacteria, viruses, fungi and other microorganisms can be found in the documents from the **sources bellow** and from **Appendix B.**

Studies shows that effect of germicidal UV light (254 nm) also kills eggs and adults of dust mites that live in the mattresses and pillows and which are second to pollen for causing allergic reactions. One of the studies can be found in **Source 5** and **Appendix C.**

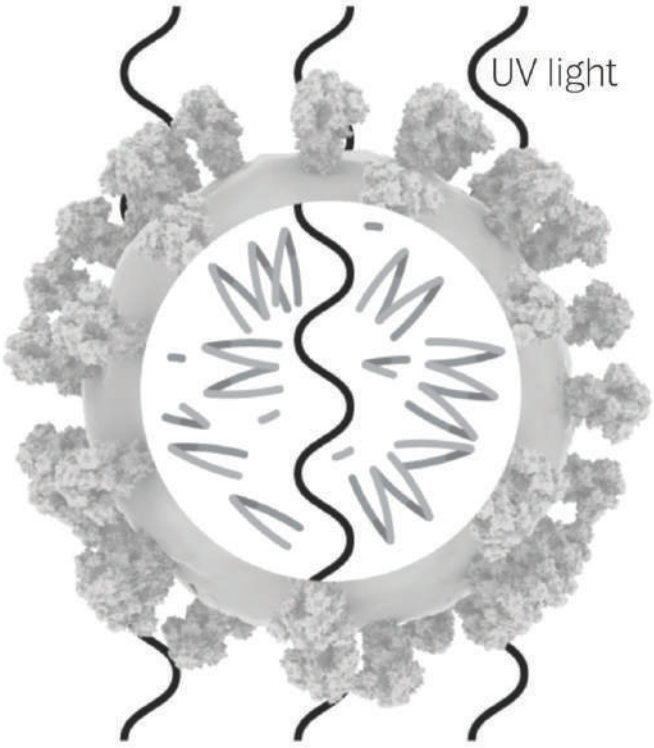
There are also studies which confirms the effects of UV disinfection process on the Ambulances which are are frequently contaminated with infectious microorganisms shed by patients during transport that can be transferred to subsequent patients and emergency medical service workers **(Source 6).**

Effects of UV-C on Corona virus

The World Health Organisations guidelines on the Coronavirus response recommends preventive hygiene practices being the best defence. In addition to this, scientific studies conclude that common pathogens and microorganisms may well survive or persist on surfaces for 24 hours to months (depending on the type), and can thereby be a continuous source of transmission if no regular preventive surface disinfection is performed **(Source 7)**

Severe acute respiratory syndrome (SARS) is a life-threatening disease caused by a novel coronavirus termed SARS-CoV. Due to the severity of this disease, the World Health Organization (WHO) recommends that manipulation of active viral cultures of SARS-CoV be performed in containment laboratories at biosafety level 3 (BSL3). The virus was inactivated by ultraviolet light (UV) at 254 nm, heat treatment of 65 °C or greater, alkaline (pH > 12) or acidic (pH < 3) conditions, formalin and glutaraldehyde treatments. We describe the kinetics of these efficient viral inactivation methods, which will allow research with SARS-CoV containing materials, that are rendered non-infectious, to be conducted at reduced safety levels. **(Source 8)**

Ultraviolet light disrupts the genetic material.



References

Source 1 - https://www.ncbi.nlm.nih.gov/pubmed/26739639

Source 2 - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4467610/

Source 3 - https://www.hps.scot.nhs.uk/web-resources-container/literature-review-and-practice-recommendations-existing-and-emerging-technologies-used-for-decontamination-of-the-healthcare-environment-uv-light/

Source 4 - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1564025/

Source 5 - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3609379/

Source 6 - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6379899/

Source 7 - (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1564025/).

(Source 8) https://doi.org/10.1016/j.jviromet.2004.06.006

Appendix A

UV rate Constants for Bacteria, Viruses, Fungi and Other Microbes

Source: Wladyslaw Kowalski, Ultraviolet Germicidal Irradiation Handbook, Immune Building Systems, Inc

UV Rate Constants for Bacteria

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	Sh	St	UL J/m^2	Dia. μm	Base Pairs kb	Source (see Chapter 4 Refs)
Acinetobacter baumannii	Veg	18	0.12800	S	-	N	1	90	1.225	3598	Rastogi 2007
Acinetobacter baumannii	Veg	33	0.19200	W	-	Y	2	48	1.225	3598	Templeton 2009
Aeromonas	Veg	11	0.20310	W	Wat	-	-	-	2.098	4740	Sako 1985
Aeromonas hydrophila	Veg	16	0.14100	W	Wat	Y	1	590	2.098	4740	Liltved 1996
B. atrophaeus (B. globigii)	Sp	144	0.01600	Air	(Lo RH)	-	-	-	1.12	4140	EPA 2006
B. atrophaeus spores	Sp	1323	0.00174	W	Wat	N	1	4000	1.12	4140	Shafaat 2006
Bacillus anthracis spores	Sp	411	0.00560	W	Wat	Y	1	600	1.118	5220	Nicholson 2003
Bacillus anthracis spores	Sp	45	0.05094	S	-	N	1	52	1.118	5220	Sharp 1939
Bacillus anthracis spores	Sp	743	0.00310	S	-	Y	2	1890	1.118	5220	Knudson 1986
Bacillus cereus spores	Sp	267	0.00863	S	-	-	-	-	1.118	5700	Weinberger 1984
Bacillus cereus spores	Sp	210	0.01098	S	-	-	-	-	1.118	5700	Weisova 1966
Bacillus cereus spores	Sp	116	0.01979	S	-	-	-	-	1.118	5700	Germaine 1973
Bacillus cereus spores	Sp	408	0.00564	S	-	-	-	-	1.118	5700	Benoit 1990
Bacillus megatherium	Sp	273	0.00843	S	-	-	-	-	1.12	4600	Hercik 1937
Bacillus megatherium	Veg	113	0.02038	S	-	-	-	-	-	4600	Hercik 1937
Bacillus pumilis spores	Sp	50	0.04600	W	Wat	Y	2	100	-	-	New combe 2005
Bacillus subtilis	Veg	25	0.09210	W	Wat	-	-	-	-	4210	Lojo 1995
Bacillus subtilis	Veg	14	0.16858	Air	(Lo RH)	N	1	940	-	4210	Nakamura 1987
Bacillus subtilis spores	Sp	250	0.00920	W	Wat	Y	1	600	1.12	4140	Nicholson 2003
Bacillus subtilis spores	Sp	161	0.01430	W	Wat	N	1	600	1.12	4140	Hoyer 2000
Bacillus subtilis spores	Sp	116	0.01982	W	Wat				1.12	4140	Sommer 1989
Bacillus subtilis spores	Sp	220	0.01047	W	Wat	N	1	500	1.12	4140	Sommer 1998
Bacillus subtilis spores	Sp	199	0.01155	W	Wat	N	1	810	1.12	4140	Sommer 1999
Bacillus subtilis spores	Sp	77	0.03000	W	Wat	Y	1	400	1.12	4140	Qualls 1983
Bacillus subtilis spores	Sp	155	0.01490	W	Wat	Y	1	400	1.12	4140	Mamane-Gravetz 2005
Bacillus subtilis spores	Sp	89	0.02580	W	Wat	-	-	-	1.12	4140	Horneck 1985
Bacillus subtilis spores	Sp	200	0.01150	W	Wat	Y	2	800	1.12	4140	Chang 1985
Bacillus subtilis spores	Sp	80	0.02880	W	Wat	Y	2	400	1.12	4140	DeGuchi 2005
Bacillus subtilis spores	Sp	94	0.02460	S	-	-	-	220	1.12	4140	Rentschler 1941
Bacillus subtilis spores	Sp	68	0.03370	S	-	-	-	-	1.12	4140	Munakata 1975
Bacillus subtilis spores	Sp	113	0.02030	S	-	-	-	-	1.12	4140	Munakata 1972
Bacillus subtilis spores	Sp	89	0.02600	Air	Hi RH	N	1	45.0	1.12	4140	Peccia 2001a
Bacillus subtilis spores	Sp	149	0.01550	Air	Lo RH	Y	1	550	1.12	4140	Ke 2009
Bacillus subtilis spores	Sp	85	0.02700	Air	Lo RH	N	1	45.0	1.12	4140	Peccia 2001a
Bacillus thuringiensis	Sp	2303	0.00100	W	Wat	N	2	10000	-	-	Griego 1978
Burkholderia cenocepacia	Veg	58	0.03956	W	Wat	N	1	60	0.707	7270	Abshire 1981
Burkholderia cepacia	Veg	11	0.21150	Air	Lo RH	N	1	23	0.77	7700	Fletcher 2004
Burkholderia cepacia	Veg	22	0.10520	Air	Hi RH	N	1	23	0.77	7700	Fletcher 2004
Campylobacter jejuni	Veg	11	0.20933	W	Wat	-	-	-	2.12	1641	Wilson 1992
Campylobacter jejuni	Veg	29	0.07940	W	Wat	-	-	-	2.12	1641	Butler 1987
Citrobacter diversus	Veg	32	0.07140	W	Wat	N	1	130	1.2	-	Giese 2000
Citrobacter freundii	Veg	42	0.05482	W	Wat	-	-	-	1.2	-	Zemke 1990
Citrobacter freundii	Veg	46	0.05010	W	Wat	N	1	130	1.2	-	Giese 2000
Clostridium perfringens	Veg	38	0.06000	W	Wat	-	-	-	5	3031	Hijnen 2006
Clostridium perfringens	Veg	135	0.01700	-	-	-	-	-	5	3031	Jepson 1973
Clostridium tetani	Veg	49	0.04699	-	-	-	-	-	5	2790	Jepson 1973
Corynebacterium diphtheriae	Veg	33	0.07010	S	-	N	1	46	0.698	2480	Sharp 1939
Coxiella burnetii	Veg	15	0.15350	W	Wat	-	-	-	0.283	2030	Little 1980
Deinococcus radiodurans	Veg	365	0.00630	W	Wat	Y	1	1200	-	3280	Setlow 1964
Enterobacter cloacae	Veg	64	0.03598	W	Wat	-	-	-	1.414	-	Zemke 1990
Escherichia coli	Veg	21	0.10900	W	Wat	N	1	21	0.5	5490	Zelle 1955
Escherichia coli	Veg	53	0.04320	W	Wat	N	1	24	0.5	5490	Tyrrell 1972
Escherichia coli	Veg	20	0.11510	W	Wat	N	1	60	0.5	5490	Oguma 2001
Escherichia coli	Veg	47	0.04940	W	Wat	N	1	900	0.5	5490	Kim 2002
Escherichia coli	Veg	43	0.05300	W	Wat	Y	1	60	0.5	5490	Hofemeister 1975
Escherichia coli	Veg	13	0.18000	W	Wat	Y	2	-	0.5	5490	Harris 1987
Escherichia coli	Veg	20	0.11500	W	Wat	Y	1	120	0.5	5490	Harm 1968
Escherichia coli	Veg	24	0.09600	W	Wat	Y	1	200	0.5	5490	David 1973
Escherichia coli	Veg	81	0.02832	W	Wat	N	1	83	0.5	5490	Abshire 1981
Escherichia coli	Veg	25	0.09398	S	-	N	1	45	0.5	5490	Sharp 1939
Escherichia coli	Veg	19	0.12000	S	Hi RH	N	1	4.4	0.5	5490	Rentschler 1942
Escherichia coli	Veg	12	0.19300	S	Lo RH	N	1	4.4	0.5	5490	Rentschler 1942
Escherichia coli	Veg	25	0.09210	S	-			22	0.5	5490	Rentschler 1941

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UV Rate Constants for Bacteria

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	Sh	St	UL J/m^2	Dia. µm	Base Pairs kb	Source (see Chapter 4 Refs)
Escherichia coli	Veg	20	0.11670	S	-	Y	1	130	0.5	5490	Quek 2008
Escherichia coli	Veg	51	0.04540	S	-	N	1	66	0.5	5490	Luckiesh 1949
Escherichia coli	Veg	34	0.06720	S	-	N	1	900	0.5	5490	Kim 2002
Escherichia coli	Veg	55	0.04187	S	-	-	-	-	0.5	5490	Hollaender 1955
Escherichia coli	Veg	8	0.28300	S	-	N	1	48	0.5	5490	Collins 1971
Escherichia coli	Veg	3	0.72300	Air	Lo RH	-	-	6	0.5	5490	Webb 1970
Escherichia coli	Veg	11	0.21800	Air	Hi RH	-	-	6	0.5	5490	Webb 1970
Escherichia coli	Veg	11	0.21900	Air	Hi RH	N	1	4.4	0.5	5490	Rentschler 1942
Escherichia coli	Veg	13	0.18100	Air	Lo RH	N	1	4.4	0.5	5490	Rentschler 1942
Escherichia coli	Veg	15	0.15611	Air	Lo RH	N	2	4	0.5	5490	Luckiesh 1949
Escherichia coli	Veg	2	0.96500	Air	Lo RH	N	1	0.5	0.5	5490	Koller 1939
Escherichia coli	Veg	11	0.20500	Air	Hi RH	N	1	0.5	0.5	5490	Koller 1939
Francisella tularensis	Veg	256	0.00900	Air	Lo RH	N	1	1	0.2	1890	Beebe 1959
Francisella tularensis	Veg	288	0.00800	Air	Hi RH	N	1	1	0.2	1890	Beebe 1959
Haemophilus influenzae	Veg	38	0.05990	S	-	Y	2	16	0.285	1910	Mongold 1992
Haemophilus influenzae Rd	Veg	13	0.17700	W	Wat	N	2	55	0.285	1910	Barnhart 1970
Halobacterium sp. NRC-1	Veg	25	0.09210	S	-	N	1	150	-	2571	Crowley 2006
Halobacterium salinarum	Veg	68	0.03390	-	-	N	1	200	-	-	Martin 2000
Halomonas elongata	Veg	13	0.18090	-	-	N	1	10	-	-	Martin 2000
Helicobacter pylori	Veg	33	0.06900	W	Wat	N	1	80	2.1	1780	Hayes 2006
Klebsiella pneumoniae	Veg	42	0.05480	W	Wat	-	-	-	0.671	5315	Zemke 1990
Klebsiella pneumoniae	Veg	68	0.03390	W	Wat	N	1	200	0.671	5315	Giese 2000
Klebsiella terrigena	Veg	33	0.07000	W	Wat	N	1	110	-	-	Wilson 1992
Legionella dumoffi	Veg	24	0.09594	S	-	N	1	72	0.52	3400	Knudson 1985
Legionella bozemanii	Veg	19	0.17400	W	Wat	Y	1	97	0.52	3400	Yamamoto 1987
Legionella bozemanii	Veg	15	0.15351	S	-	N	2	72	0.52	3400	Knudson 1985
Legionella gormanii	Veg	26	0.08856	S	-	N	1	72	0.52	3400	Knudson 1985
Legionella jordanis	Veg	11	0.20933	S	-	N	1	72	0.52	3400	Knudson 1985
Legionella longbeach	Veg	11	0.20933	S	-	N	1	72	0.52	3400	Knudson 1985
Legionella micdadei	Veg	15	0.15351	S	-	N	1	72	0.52	3400	Knudson 1985
Legionella oakridgensis	Veg	22	0.10466	S	-	N	1	72	0.52	3400	Knudson 1985
Legionella pneumophila	Veg	13	0.17400	W	Wat	Y	1	97	0.52	3400	Yamamoto 1987
Legionella pneumophila	Veg	12	0.19298	W	Wat	Y	1	0.5	0.52	3400	Gilpin 1985
Legionella pneumophila	Veg	9	0.24849	W	Wat	N	1	30	0.52	3400	Antopol 1979
Legionella pneumophila	Veg	5	0.44613	S	-	N	2	72	0.52	3400	Knudson 1985
Legionella pneumophila	Veg	25	0.09110	W	Wat	N	1	72	0.52	3400	Wilson 1992
Legionella pneumophila	Veg	16	0.14390	W	Wat	N	1	80	0.52	3400	Oguma 2004 (LP)
Legionella pneumophila	Veg	19	0.12020	W	Wat	N	1	96	0.52	3400	Oguma 2004 (MP)
Legionella wadsworthii	Veg	4	0.57565	S	-	N	2	72	0.52	3400	Knudson 1985
Listeria monocytogenes	Veg	181	0.01270	W	Wat	N	1	900	0.707	3130	Kim 2002
Listeria monocytogenes	Veg	156	0.01480	S	-	N	1	900	0.707	3130	Kim 2002
Listeria monocytogenes	Veg	10	0.23030	S	-	Y	1	48	0.707	3130	Collins 1971
Micrococcus candidus	Veg	61	0.03806	S	-	-	-	-	1.2	4050	Hollaender 1955
Micrococcus piltonensis	Veg	81	0.02843	S	-	-	-	132	2.2	-	Rentschler 1941
Micrococcus sphaeroides	Veg	100	0.02303	S	-	-	-	154	1.2	4050	Rentschler 1941
Moraxella	Veg	10965	0.00022	W	Wat	N	1	5940	1.225	1940	Keller 1982
Mycobacterium avium-intra.	Veg	84	0.02740	W	Wat	Y	1	200	1.118	5470	David 1973
Mycobacterium avium	Veg	60	0.03840	W	Wat	Y	1	20	1.118	5470	Shin 2008
Mycobacterium avium	Veg	35	0.06580	W	Wat	-	-	-	1.118	5470	McCarthy 1974
Mycobacterium bovis BCG	Veg	22	0.10550	S	-	N	1	48	0.637	4340	Collins 1971
Mycobacterium bovis BCG	Veg	10	0.24200	Air	50	N	1	5.0	0.637	4340	Riley 1976
Mycobacterium bovis BCG	Veg	12	0.19000	Air	-	-	-	-	0.637	4340	Peccia 2002
Mycobacterium bovis BCG	Veg	19	0.12000	Air	Lo RH	N	1	8.3	0.637	4340	Ko 2000
Mycobacterium bovis BCG	Veg	33	0.07000	Air	Hi RH	N	1	8.3	0.637	4340	Ko 2000
Mycobacterium flaviscens	Veg	120	0.01919	W	Wat	Y	1	200	0.637	-	David 1973
Mycobacterium fortuitum	Veg	68	0.03390	W	Wat	Y	1	200	0.637	5000	David 1973
Mycobacterium fortuitum	Veg	96	0.02400	W	Wat	Y	1	891	0.637	5000	David 1971
Mycobacterium kansasii	Veg	80	0.02880	W	Wat	Y	1	200	0.637	4345	David 1973
Mycobacterium marinum	Veg	76	0.03030	W	Wat	Y	1	200	0.637	6485	David 1973
Mycobacterium marinum	Veg	743	0.00310	W	Wat	Y	1	1782	0.637	6485	David 1971
Mycobacterium parafortuitum	Veg	13	0.18000	Air	50	N	1	45.0	0.637	-	Peccia 2001
Mycobacterium parafortuitum	Veg	46	0.05000	Air	95	N	1	45.0	0.637	-	Peccia 2001
Mycobacterium parafortuitum	Veg	19	0.12000	Air	50	N	1	-	0.637	-	Xu 2003

UV Rate Constants for Bacteria

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	Sh	St	UL J/m^2	Dia. µm	Base Pairs kb	Source (see Chapter 4 Refs)
Mycobacterium phlei	Veg	76	0.03030	W	Wat	Y	1	200	0.637	6000	David 1973
Mycobacterium phlei	Veg	63	0.03650	Air	50	N	1	5.0	0.637	6000	Riley 1976
Mycobacterium phlei	Veg	23	0.10000	Air	50	-	-	-	0.637	6000	Kethley 1973
Mycobacterium phlei	Veg	16	0.14000	Air	50	-	-	-	0.637	6000	Gillis 1974
Mycobacterium smegmatis	Veg	108	0.02130	W	Wat	Y	1	200	0.637	6980	David 1973
Mycobacterium smegmatis	Veg	1047	0.00220	W	Wat	Y	1	2430	0.637	6980	David 1971
Mycobacterium smegmatis	Veg	68	0.03400	W	Wat	Y	2	500	0.637	6980	Boshoff 2003
Mycobacterium smegmatis	Veg	12	0.19000	Air	50	-	-	-	0.637	6980	Gillis 1974
Mycobacterium terrae	Veg	50	0.04610	W	Wat	N	1	100	0.637	-	Bohrerova 2006
Mycobacterium tuberculosis	Veg	28	0.08220	W	Wat	Y	1	200	0.637	4400	David 1973
Mycobacterium tuberculosis	Veg	77	0.03000	W	Wat	Y	1	567	0.637	4400	David 1971
Mycobacterium tuberculosis	Veg	74	0.03100	W	Wat	Y	2	500	0.637	4400	Boshoff 2003
Mycobacterium tuberculosis	Veg	11	0.21320	S	-	N	1	48	0.637	4400	Collins 1971
Mycobacterium tuberculosis	Veg	5	0.47210	Air	50	N	1	5.0	0.637	4400	Riley 1976
Mycoplasma arthritidis	Veg	7	0.31240	S	-	Y	1	22	0.177	816	Furness 1977
Mycoplasma fermentans	Veg	9	0.25220	S	-	Y	1	22	0.177	816	Furness 1977
Mycoplasma hominis	Veg	7	0.32710	S	-	Y	1	22	0.177	816	Furness 1977
Mycoplasma Orale type 1	Veg	11	0.21800	S	-	Y	1	22	0.177	816	Furness 1977
Mycoplasma Orale type 2	Veg	6	0.38760	S	-	Y	1	22	0.177	816	Furness 1977
Mycoplasma pneumoniae	Veg	8	0.27910	S	-	Y	1	22	0.177	816	Furness 1977
Mycoplasma salivarium	Veg	11	0.21140	S	-	Y	1	22	0.177	816	Furness 1977
Myxobolus cerebralis	Veg	10011	0.00023	W		Y	2	10000	-	-	Hedrick 2000
Neisseria catarrhalis	Veg	44	0.05233	S	-	-	-	121	0.177	816	Rentschler 1941
Nocardia asteroides	Veg	280	0.00822	S	-	-	-	280	1.118	6021	Chick 1963
Phytomonas tumefaciens	Veg	44	0.05233	S	-	-	-	110	-	-	Rentschler 1941
Proteus mirabilis	Veg	8	0.28900	W	Wat	N	1	60	0.494	4063	Hofemeister 1975
Proteus vulgaris	Veg	30	0.07675	S	-			70	0.291	3462	Rentschler 1941
Pseudomonas aeruginosa	Veg	10	0.22692	W	Wat	Y	1	0.4	0.494	5900	Gilpin 1985
Pseudomonas aeruginosa	Veg	172	0.01340	W	Wat	N	2	770	0.494	5900	Dolman 1989
Pseudomonas aeruginosa	Veg	36	0.06600	W	Wat	N	1	340	0.494	5900	Abshire 1981
Pseudomonas aeruginosa	Veg	55	0.04190	W	Wat	N	1	55	0.494	5900	Zelle 1955
Pseudomonas aeruginosa	Veg	55	0.04187	S	-	-	-	-	0.494	5900	Hollaender 1955
Pseudomonas aeruginosa	Veg	22	0.10470	S	-	N	1	20	0.494	5900	Elasri 1999
Pseudomonas aeruginosa	Veg	10	0.23750	S	-	N	2	48	0.494	5900	Collins 1971
Pseudomonas aeruginosa	Veg	4	0.57210	Air	(Lo RH)	N	1	248	0.494	5900	Sharp 1940
Pseudomonas diminuta	Veg	96	0.02391	W	Wat	N	1	118	0.5	-	Abshire 1981
Pseudomonas fluorescens	Veg	35	0.06579	S	-	-	-	70	0.5	6438	Rentschler 1941
Pseudomonas fluorescens	Veg	3	0.47730	Air	50	N	1	13	0.5	6438	vanOsdell 2002
Pseudomonas maltophilia	Veg	70	0.03294	W	Wat	N	1	71	0.5	-	Abshire 1981
Pseudomonas putrefaciens	Veg	87	0.02662	W	Wat	N	1	89	0.5	-	Abshire 1981
Rickettsia prowazekii	Veg	13	0.17600	W	Wat	N	2	6700	0.6	1110	Allen 1954
Salmonella spp.	Veg	11	0.21380	W	Wat	N	2	20	0.8	4746	Yaun 2003
Salmonella anatum	Veg	60	0.03840	W	Wat	N	1	150	0.8	-	Tosa 1998
Salmonella derby	Veg	36	0.06360	W	Wat	N	1	75	0.8	-	Tosa 1998
Salmonella enteritidis	Veg	10	0.22100	S	-	N	1	48	0.8	4746	Collins 1971
Salmonella enteritidis	Veg	33	0.07010	W	Wat	N	1	100	0.8	4746	Tosa 1998
Salmonella infantis	Veg	20	0.11510	W	Wat	N	1	60	0.8	-	Tosa 1998
Salmonella typhi	Veg	21	0.10760	W	Wat	N	1	21	0.806	4791	Zelle 1955
Salmonella typhi	Veg	30	0.07675	W	Wat	Y	1	100	0.806	4791	Chang 1985
Salmonella typhi	Veg	21	0.10760	S	-	N	1	40	0.806	4791	Sharp 1939
Salmonella typhi	Veg	9	0.25580	W	Wat	N	2	18	0.806	4791	Wilson 1992
Salmonella typhimurium	Veg	295	0.00780	W	Wat	N	1	900	0.8	4950	Kim 2002
Salmonella typhimurium	Veg	18	0.12830	W	Wat	N	2	50	0.8	-	Tosa 1998
Sarcina lutea	Veg	197	0.01169	S	-	-	-	264	1.48	-	Rentschler 1941
Serratia indica	Veg	209	0.01100	Air	42-51	N	1	370	0.632	-	Harstad 1954
Serratia marcescens	Veg	22	0.10490	W	Wat	N	1	22	0.632	5114	Zelle 1955
Serratia marcescens	Veg	105	0.02194	W	Wat	-	-	-	0.632	5114	Harris 1993
Serratia marcescens	Veg	22	0.10470	S	-	N	1	39	0.632	5114	Sharp 1939
Serratia marcescens	Veg	22	0.10466	S	-	-	-	70	0.632	5114	Rentschler 1941
Serratia marcescens	Veg	8	0.27742	S	-	-	-	-	0.632	5114	Hollaender 1955
Serratia marcescens	Veg	10	0.22080	S	-	N	1	48	0.632	5114	Collins 1971
Serratia marcescens	Veg	2	0.93900	Air	Lo RH	Y	2	40	0.632	5114	Fletcher 2003
Serratia marcescens	Veg	24	0.09500	Air	Hi RH	Y	2	40	0.632	5114	Fletcher 2003

UV Rate Constants for Bacteria

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	Sh	St	UL J/m^2	Dia. µm	Base Pairs kb	Source (see Chapter 4 Refs)
Serratia marcescens	Veg	8	0.28670	Air	25-57	N	1	31	0.632	5114	UVDI 2001
Serratia marcescens	Veg	4	0.57500	Air	22-33	N	1	8.3	0.632	5114	Ko 2000
Serratia marcescens	Veg	115	0.02000	Air	Hi RH	N	1	8.3	0.632	5114	Ko 2000
Serratia marcescens	Veg	5	0.44490	Air	(Lo RH)	Y	1	248	0.632	5114	Sharp 1940
Serratia marcescens	Veg	20	0.11300	Air	(Lo RH)	Y	1	940	0.632	5114	Nakamura 1987
Serratia marcescens	Veg	33	0.07000	Air	95	N	1	45.0	0.632	5114	Peccia 2001
Serratia marcescens	Veg	3	0.92000	Air	68	N	1	2	0.632	5114	Lai 2004
Serratia marcescens	Veg	3	0.43050	Air	50	N	1	13	0.632	5114	vanOsdell 2002
Serratia marcescens	Veg	5	0.45000	Air	50	N	1	45.0	0.632	5114	Peccia 2001
Serratia marcescens	Veg	1	2.20000	Air	36	N	1	2	0.632	5114	Lai 2004
Shigella dysenteriae	Veg	18	0.13080	W	Wat	-	-	-	0.801	4369	Wilson 1992
Shigella paradysenteriae	Veg	17	0.13706	S	-	N	1	40	0.801	-	Sharp 1939
Shigella sonnei	Veg	18	0.12500	W	Wat	Y	1	100	0.801	-	Chang 1985
Spirillum rubrum	Veg	44	0.05233	S	-	-	-	88	-	-	Rentschler 1941
Staphylococcus albus	Veg	18	0.12514	S	-	Y	1	25	1.06	2900	Sharp 1939
Staphylococcus albus	Veg	33	0.06978	S	-	-	-	62	1.06	2900	Rentschler 1941
Staphylococcus albus (1)	Veg	23	0.09950	Air	(Lo RH)	N	1	4.4	1.06	2900	Rentschler 1942
Staphylococcus albus (2)	Veg	52	0.04400	Air	(Lo RH)	N	1	4.4	1.06	2900	Rentschler 1942
Staphylococcus aureus	Veg	52	0.04400	W	Wat	N	2	770	0.866	2800	Dolman 1989
Staphylococcus aureus	Veg	27	0.08531	W	Wat	Y	2	150	0.866	2800	Chang 1985
Staphylococcus aureus	Veg	56	0.04134	W	Wat	N	1	58	0.866	2800	Abshire 1981
Staphylococcus aureus	Veg	30	0.07700	S	-	N	1	4	0.866	2800	Sturm 1932
Staphylococcus aureus	Veg	50	0.04652	S	-	-	-	-	0.866	2800	Hollaender 1955
Staphylococcus aureus	Veg	66	0.03500	S	-	N	1	30	0.866	2800	Gates 1934
Staphylococcus aureus	Veg	26	0.08860	S	-	N	1	35	0.866	2800	Sharp 1939
Staphylococcus aureus	Veg	37	0.06240	S	-	N	1	48	0.866	2800	Luckiesh 1949
Staphylococcus aureus	Veg	19	0.11840	S	-	N	2	33	0.866	2800	Gates 1929
Staphylococcus aureus	Veg	20	0.11300	Air	(Lo RH)	N	1	940	0.866	2800	Nakamura 1987
Staphylococcus aureus	Veg	7	0.34760	Air	(Lo RH)	N	1	248	0.866	2800	Sharp 1940
Staphylococcus aureus	Veg	2	0.96020	Air	-	N	2	3	0.866	2800	Luckiesh 1949
Staphylococcus aureus	Veg	2	0.96200	Air	(Lo RH)	-	-	-	0.866	2800	Luckiesh 1946
Staphylococcus epidermis	Veg	161	0.01433	W	Wat	-	-	-	0.866	2640	Harris 1993
Staphylococcus epidermis	Veg	14	0.16210	Air	50	N	1	10	0.866	2640	vanOsdell 2002
Staphylococcus epidermis	Veg	29	0.00800	Air	85	N	1	10	0.866	2640	vanOsdell 2002
Staphylococcus epidermis	Veg	20	0.11300	Air	(Lo RH)	N	1	940	0.866	2640	Nakamura 1987
Staphylococcus epidermis	Veg	22	0.10500	Air	(Lo RH)	N	1	56	0.866	2640	Furuhashi 1989
Streptococcus agalactiae	Veg	5	0.43420	Air	-	N	2	7	0.707	2127	Luckiesh 1949
Streptococcus faecalis	Veg	55	0.09200	W	Wat	Y	2	150	0.707	-	Chang 1985
Streptococcus faecalis	Veg	195	0.01180	W	Wat	N	2	500	0.707	-	Sanz 2007
Streptococcus faecalis	Veg	31	0.07540	W	Wat	Y	2	150	0.707	-	Harris 1987
Streptococcus faecalis	Veg	120	0.01919	W	Wat	N	1	121	0.707	-	Abshire 1981
Streptococcus faecium	Veg	45	0.05100	W	Wat	N	1	350	0.632	5114	Martiny 1988
Streptococcus haemolyticus	Veg	22	0.10660	S	-	N	1	35	0.707	2680	Sharp 1939
Streptococcus lactis	Veg	62	0.03744	S	-	-	-	88	0.707	-	Rentschler 1941
Streptococcus pneumoniae	Veg	468	0.00492	S	-	-	1	3000	0.707	-	Gritz 1990
Streptococcus pyogenes	Veg	4	0.06161	S	-	N	2	94	0.894	1900	Lidw ell 1950
Streptococcus pyogenes	Veg	1	1.56100	Air	-	N	2	2	0.894	1900	Luckiesh 1949
Streptococcus viridans	Veg	20	0.11513	S	-	N	1	32	0.707	-	Sharp 1939
Streptomyces coelicolor	Veg	60	0.03840	W	Wat	N	1	120	-	8667	Jagger 1970
Streptomyces griseus	Veg	129	0.01780	W	Wat	N	1	672	-	8545	Kelner 1949
Streptomyces griseus	Veg	60	0.03840	W	Wat	N	1	120	-	8545	Jagger 1970
Vibrio anguillarum (fish)	Veg	10	0.23820	W	Wat	-	-	-	2.12	-	Sako 1985
Vibrio anguillarum (fish)	Veg	5	0.42600	W	Wat	N	2	27	2.12	-	Liltved 1995
Vibrio cholerae	Veg	17	0.13400	W	Wat	-	-	-	2.12	4148	Wilson 1992
Vibrio ordalii	Veg	18	0.12560	W	Wat	-	-	-	2.12	-	Sako 1985
Vibrio parahaemolyticus	Veg	8	0.30700	W	Wat	N	1	30	2.12	5165	Nozu 1977
Vibrio salmonicida (fish)	Veg	5	0.42600	W	Wat	N	2	27	-	-	Liltved 1995
Yersinia enterocolitica	Veg	15	0.15351	W	Wat	-	-	-	0.707	4615	Butler 1987
Yersinia enterocolitica	Veg	28	0.08127	W	Wat	-	-	-	0.707	4615	Carlson 1975
Yersinia enterocolitica	Veg	11	0.20467	W	Wat	-	-	-	0.707	4615	Butler 1987
Yersinia enterocolitica	Veg	13	0.17170	W	Wat	N	1	46	0.707	4615	Wilson 1992
Yersinia ruckeri (fish)	Veg	5	0.42600	W	Wat	N	2	-	-	-	Liltved 1995
Yersinia ruckeri (fish)	Veg	10	0.23020	W	Wat	N	2	30	-	-	Liltved 1996

UV Rate Constants for Viruses

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	Sh	St	UL J/m^2	Dia. µm	Base Pairs kb	Source (see Chapter 4 Refs)
Adenovirus	dsDNA	34	0.06800	Air	Hi RH	N	1	26	0.079	35.937	Walker 2007
Adenovirus	dsDNA	59	0.03900	Air	Lo RH	N	1	26	0.079	35.937	Walker 2007
Adenovirus	dsDNA	42	0.05500	Air	50	N	1	68	0.079	36.001	Jensen 1964
Adenovirus	dsDNA	903	0.00255	W	Wat	N	1	900	0.079	36.001	Wasserman 1962
Adenovirus type 1	dsDNA	299	0.00770	W	Wat	-	-	300	0.079	36.001	Battiggelli 1993
Adenovirus type 1	dsDNA	350	0.00658	W	Wat	N	1	1200	0.079	36.001	Nw achuku 2005
Adenovirus type 2	dsDNA	400	0.00576	S	-	N	1	1200	0.079	35.937	Day 1974
Adenovirus type 2	dsDNA	640	0.00360	W	Wat	N	1	480	0.079	35.937	Rainbow 1970
Adenovirus type 2	dsDNA	490	0.00470	W	Wat	N	2	400	0.079	36.001	Rainbow 1973
Adenovirus type 2	dsDNA	533	0.00432	W	Wat	N	1	1200	0.079	35.937	Linden 2007 (LP lamp)
Adenovirus type 2	dsDNA	150	0.01540	W	Wat	N	1	1200	0.079	35.937	Linden 2007 (MP lamp)
Adenovirus type 2	dsDNA	300	0.00768	W	Wat	N	1	60	0.079	35.937	Shin 2005
Adenovirus type 2	dsDNA	400	0.00576	W	Wat	N	1	3000	0.079	35.937	Gerba 2002
Adenovirus type 2	dsDNA	276	0.00834	W	Wat	N	1	1000	0.079	35.937	Ballester 2004
Adenovirus type 4	dsDNA	921	0.00250	W	Wat	N	1	1200	0.079	35.937	Nw achuku 2005
Adenovirus type 15	dsDNA	396	0.00581	W	Wat	N	1	2100	0.079	35.937	Thompson 2003
Adenovirus type 40	dsDNA	300	0.00768	S	-	N	1	1240	0.069	36.001	Meng 1996
Adenovirus type 40	dsDNA	546	0.00422	W	Wat	N	1	200	0.069	36.001	Thurston-Enriquez 2003
Adenovirus type 41	dsDNA	240	0.00976	S	-	N	1	1118	0.069	36.001	Meng 1996
Adenovirus type 41	dsDNA	425	0.00542	W	Wat	-	-	-	0.069	36.001	Malley 2004
Adenovirus type 41	dsDNA	555	0.00415	W	Wat	N	1	300	0.069	36.001	Ko 2005
Adenovirus type 41	dsDNA	600	0.00384	W	Wat	N	1	12	0.069	36.001	Durance 2005
Adenovirus type 5	dsDNA	400	0.00576	W	Wat	N	1	12	0.084	35.938	Durance 2005
Adenovirus type 5	dsDNA	541	0.00426	W	Wat	N	1	2160	0.084	36.598	Wang 2004
Adenovirus type 5	dsDNA	720	0.00320	W	Wat	N	1	1200	0.084	35.598	Nw achuku 2005
Adenovirus type 6	dsDNA	390	0.00590	W	Wat	N	1	1200	0.079	35.937	Nw achuku 2005
Adenovirus type 6	dsDNA	400	0.00576	W	Wat	-	-	-	0.079	35.937	Battiggelli 1993
AHNV (fish virus)	ssRNA	349	0.00660	W	Wat	-	-	-	-	-	Liltved 2005
Avian Influenza virus	ssRNA	22	0.10600	W	Wat	N	2	97	0.09	-	Lucio-Forster 2006
Avian Influenza virus	ssRNA	30	0.07680	W	Wat	-	-	-	0.098	-	Deshmukh 1968
Avian Leukosis virus (RSA)	ssRNA	631	0.00365	W	Wat	N	1	1620	0.107	7.286	Levinson 1966
Avian Sarcoma virus	ssDNA	155	0.01490	W	Wat	N	1	372	0.098	7	Owada 1976
Avian Sarcoma virus	ssDNA	381	0.00604	W	Wat	N	1	768	0.098	7	Bister 1977
B. subtilis phage 029	dsDNA	70	0.03289	W	Wat	-	-	-	-	-	Freeman 1987
B. subtilis phage SP02c12	dsDNA	100	0.02303	W	Wat	-	-	-	0.087	44.01	Freeman 1987
B. subtilis phage SPP1	dsDNA	195	0.01181	W	Wat	-	-	-	0.087	44.01	Freeman 1987
Bacteriophage B40-8	dsDNA	137	0.01679	W	Wat	Y	1	400	-	-	Sommer 2001
Bacteriophage F-specific	dsRNA	292	0.00789	W	Wat	N	1	300	0.025	-	Havelaar 1987
Bacteriophage MS2	ssRNA	26	0.04800	Air	Hi RH	N	1	26	0.02	3.569	Walker 2007
Bacteriophage MS2	ssRNA	61	0.03800	Air	Lo RH	N	1	26	0.02	3.569	Walker 2007
Bacteriophage MS2	ssRNA	3	0.81000	Air	Lo RH	N	1	12	0.02	3.569	Tseng 2005
Bacteriophage MS2	ssRNA	4	0.64000	Air	Hi RH	N	1	12	0.02	3.569	Tseng 2005
Bacteriophage MS2	ssRNA	606	0.00380	W	Wat	N	1	110	0.02	3.569	Furuse 1971
Bacteriophage MS2	ssRNA	135	0.01710	W	Wat	N	1	301	0.02	3.569	Tree 1997
Bacteriophage MS2	ssRNA	427	0.00539	W	Wat	N	1	600	0.02	3.569	Sommer 2001
Bacteriophage MS2	ssRNA	193	0.01190	W	Wat	N	1	360	0.02	3.569	Sommer 1998
Bacteriophage MS2	ssRNA	419	0.00550	W	Wat	Y	1	600	0.02	3.569	Mamane-Gravetz 2005
Bacteriophage MS2	ssRNA	368	0.00625	W	Wat	N	1	600	0.02	3.569	Templeton 2006
Bacteriophage MS2	ssRNA	295	0.00780	W	Wat	N	1	201	0.02	3.569	Ko 2005
Bacteriophage MS2	ssRNA	40	0.05760	W	Wat	N	2	40	0.02	3.569	Weidenmann 1993
Bacteriophage MS2	ssRNA	173	0.01330	W	Wat	N	1	1090	0.02	3.569	Wilson 1992
Bacteriophage MS2	ssRNA	275	0.00837	W	Wat	N	1	200	0.02	3.569	Thurston-Enriquez 2003
Bacteriophage MS2	ssRNA	217	0.01060	W	Wat	N	1	920	0.02	3.569	Batch 2004
Bacteriophage MS2	ssRNA	250	0.00920	W	Wat	N	1	250	0.02	3.569	Battiggelli 1993
Bacteriophage MS2	ssRNA	217	0.01060	W	Wat	N	1	1500	0.02	3.569	Simonet 2006
Bacteriophage MS2	ssRNA	217	0.01063	W	Wat	N	1	800	0.02	3.569	deRodaHusman 2004
Bacteriophage MS2	ssRNA	213	0.01080	W	Wat	N	1	400	0.02	3.569	Butkus 2004
Bacteriophage MS2	ssRNA	187	0.01230	W	Wat	-	-	-	0.02	3.569	Oppenheimer 1997
Bacteriophage MS2	ssRNA	169	0.01360	W	Wat	N	1	800	0.02	3.569	Nuanualsuwan 2002
Bacteriophage MS2	ssRNA	164	0.01402	W	Wat	N	1	900	0.02	3.569	Rauth 1965
Bacteriophage MS2	ssRNA	150	0.01540	W	Wat	N	1	30	0.02	3.569	Shin 2005
Bacteriophage MS2	ssRNA	140	0.01640	W	Wat	N	1	-	0.02	3.569	Meng 1996
Bacteriophage MS2	ssRNA	198	0.01160	W	Wat	N	1	1520	0.02	3.569	Nieuwstad 1994

UV Rate Constants for Viruses

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	Sh	St	UL J/m^2	Dia. µm	Base Pairs kb	Source (see Chapter 4 Refs)
Bacteriophage MS2	ssRNA	228	0.01010	W	Wat	N	1	1550	0.02	3.569	Lazarova 2004
Bacteriophage MS2	ssRNA	245	0.00940	W	Wat	N	1	-	0.02	3.569	Thompson 2003
Bacteriophage Qβ	ssRNA	125	0.01840	W	Wat	N	1	1500	-	-	Simonet 2006
Bacteriophage Qβ	ssRNA	1919	0.00120	W	Wat	N	1	2500	-	-	O'Hara 1980
Berne virus	ssRNA	13	0.18420	W	Wat	-	-	-	0.13	20	Weiss 1986
BF-NNV (fish virus)	ssRNA	501	0.00460	W	Wat	-	-	-	-	-	Yoshimizu 2005
BLV	ssRNA	1799	0.00128	W	Wat	Y	2	400	0.1	8.419	Shimizu 2004
BLV	ssRNA	221	0.01040	W	Wat	N	1	1000	0.1	8.419	Guillemain 1981
Borna virus	ssRNA	79	0.02920	W	Wat	-	-	-	0.09	8.91	Danner 1979
Bovine Calicivirus	ssDNA	95	0.02420	W	Wat	-	-	-	0.02	7.45	Malley 2004
Bovine Parvovirus	ssDNA	35	0.06580	W	-	-	-	-	0.02	5.517	vonBrodorotti 1982
Canine Calicivirus	ssRNA	67	0.03450	W	Wat	N	1	800	0.037	8.513	deRodaHusman 2004
Canine hepatic Adenovirus	dsDNA	265	0.00869	W	Wat	-	-	-	0.08	36.5	vonBrodorotti 1982
CCHV (fish virus)	dsDNA	5	0.46050	W	Wat	-	-	-	-	130	Yoshimizu 2005
Cholera phage Kappa	dsDNA	634	0.00363	W	Wat	N	1	1919	-	-	Samad 1987
Coliphage f2	ssRNA	310	0.00743	W	Wat	-	-	-	-	-	Severin 1983
Coliphage fd	ssDNA	23	0.09940	W	Wat	N	1	900	-	-	Rauth 1965
Coliphage ϕX-174	ssDNA	3	0.71000	Air	Lo RH	N	1	12	0.025	5.386	Tseng 2005
Coliphage ϕX-174	ssDNA	4	0.53000	Air	Hi RH	N	1	12	0.025	5.386	Tseng 2005
Coliphage ϕX-174	ssDNA	18	0.12800	W	Wat	N	1	42	0.025	5.386	Yarus 1964
Coliphage ϕX-174	ssDNA	21	0.11140	W	Wat	N	1	90	0.025	5.386	Setlow 1960
Coliphage ϕX-174	ssDNA	21	0.11090	W	Wat	N	1	900	0.025	5.386	Rauth 1965
Coliphage ϕX-174	ssDNA	30	0.07650	W	Wat	-	-	-	0.025	5.386	Proctor 1972
Coliphage ϕX-174	ssDNA	25	0.09200	W	Wat	N	2	2000	0.025	5.386	Gurzadyan 1981
Coliphage ϕX-174	ssDNA	14	0.16060	W	Wat	-	-	-	0.025	5.386	David 1964
Coliphage ϕX-174	ssDNA	25	0.09350	W	Wat	N	1	105	0.025	5.386	Sommer 1998
Coliphage ϕX-174	ssDNA	57	0.04013	W	Wat	N	1	130	0.025	5.386	Sommer 2001
Coliphage ϕX-174	ssDNA	177	0.01300	W	Wat	N	1	800	0.025	5.386	Nuanualsuwan 2002
Coliphage ϕX-174	ssDNA	23	0.10230	W	Wat	N	1	150	0.025	5.386	Battigelli 1993
Coliphage ϕX-174	ssDNA	40	0.05760	W	Wat	N	1	120	0.025	5.386	Oppenheimer 1993
Coliphage ϕX-174	ssDNA	18	0.12910	W	Wat	N	1	70	0.025	5.386	Giese 2000
Coliphage lambda	dsDNA	57	0.04050	W	Wat	N	2	600	0.05	168.9	Gurzadyan 1981
Coliphage lambda	dsDNA	70	0.03310	W	Wat	-	-	-	0.05	168.9	Harm 1961
Coliphage lambda	dsDNA	72	0.03200	W	Wat	Y	1	-	0.05	168.9	Weigle 1953
Coliphage lambda	dsDNA	184	0.01250	W	Wat	N	2	1100	0.05	168.9	Davidovich 1991
Coliphage PRD1	dsDNA	87	0.02650	S	-	N	1	-	0.062	14.925	Meng 1996
Coliphage PRD1	dsDNA	20	0.11500	W	Wat	N	1	10	0.062	14.925	Shin 2005
Coliphage T1	dsDNA	6	0.36970	W	Wat	-	-	-	0.05	48.836	Hotz 1969
Coliphage T1	dsDNA	38	0.06000	W	Wat	N	1	200	0.05	48.836	Harm 1968
Coliphage T1	dsDNA	40	0.05800	W	Wat	N	1	60	0.05	48.836	Fluke 1949 (265 nm)
Coliphage T2	dsDNA	5	0.48400	W	Wat	N	1	900	0.065	-	Rauth 1965
Coliphage T2	dsDNA	9	0.25600	W	Wat	-	-	-	0.065	-	Jagger 1956
Coliphage T2	dsDNA	133	0.01730	W	Wat	Y	1	927	0.065	-	Dulbecco 1952
Coliphage T3	dsDNA	10	0.23100	W	Wat	Y	1	-	0.045	-	Winkler 1962
Coliphage T4	dsDNA	7	0.34500	W	Wat	N	1	60	0.089	168.9	Otaki 2003
Coliphage T4	dsDNA	14	0.16850	W	Wat	N	1	19	0.089	168.9	Ross 1971
Coliphage T4	dsDNA	15	0.15400	W	Wat	N	1	40	0.089	168.9	Harm 1968
Coliphage T4	dsDNA	29	0.08000	W	Wat	N	1	50	0.089	168.9	Templeton 2006
Coliphage T4	dsDNA	22	0.10700	W	Wat	Y	1	-	0.089	168.9	Winkler 1962
Coliphage T4	dsDNA	12	0.20000	W	Wat	N	2	40	0.089	168.9	Bohrerova 2008
Coliphage T7	dsDNA	7	0.33000	Air	Lo RH	N	1	12	0.063	39.937	Tseng 2005
Coliphage T7	dsDNA	10	0.22000	Air	Hi RH	N	1	12	0.063	39.937	Tseng 2005
Coliphage T7	dsDNA	95	0.02420	W	Wat	N	1	-	0.063	39.937	Benzer 1952
Coliphage T7	dsDNA	53	0.04320	W	Wat	N	1	180	0.063	39.937	Peak 1978 (B)
Coliphage T7	dsDNA	41	0.05600	W	Wat	Y	1	200	0.063	39.937	Bohrerova 2008 (LP)
Coliphage T7	dsDNA	38	0.06100	W	Wat	Y	1	200	0.063	39.937	Bohrerova 2008 (MP)
Coliphage T7	dsDNA	23	0.10000	W	Wat	N	1	-	0.063	39.937	Ronto 1992
Coliphage T7	dsDNA	11	0.20470	W	Wat	N	1	45	0.063	39.937	Peak 1978 (Bs-1)
Coronavirus	ssRNA	3	0.37700	Air	50	N	1	6	0.113	30.738	Walker 2007
Coronavirus	ssRNA	7	0.32100	W	Wat	-	-	-	0.113	30.738	Weiss 1986
Coronavirus (SARS)	ssRNA	226	0.01000	W	Wat	N	2	1200	0.113	29.751	Kariwa 2004
Coronavirus (SARS)	ssRNA	3046	0.00076	W	Wat	N	2	14458	0.113	29.751	Darnell 2004
Coxsackievirus	ssRNA	21	0.11100	Air	60	N	1	68	0.027	7.413	Jensen 1964

UV Rate Constants for Viruses

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	Sh	St	UL J/m^2	Dia. µm	Base Pairs kb	Source (see Chapter 4 Refs)
Coxsackievirus	ssRNA	128	0.02000	W	Wat	N	1	348	0.027	7.413	Hill 1970
Coxsackievirus	ssRNA	86	0.02684	W	Wat	N	1	300	0.027	7.413	Havelaar 1987
Coxsackievirus B3	ssRNA	80	0.02878	W	Wat	N	1	400	0.027	7.413	Gerba 2002
Coxsackievirus B4	ssRNA	60	0.03840	W	Wat	N	1	30	0.027	7.413	Shin 2005
Coxsackievirus B5	ssRNA	95	0.02424	W	Wat	N	1	400	0.027	7.413	Gerba 2002
Coxsackievirus B5	ssRNA	72	0.03180	W	Wat	N	1	200	0.027	7.413	Battigelli 1993
CSV (fish virus)	dsRNA	501	0.00460	W	Wat	-	-	1000	-	-	Yoshimizu 2005
Echovirus (Parechovirus)	ssRNA	106	0.02190	W	Wat	N	1	348	0.024	7.354	Hill 1970
Echovirus 1	ssRNA	80	0.02878	W	Wat	N	1	400	0.024	7.354	Gerba 2002
Echovirus 2	ssRNA	70	0.03289	W	Wat	N	1	400	0.024	7.354	Gerba 2002
Encephalomyocarditis virus	ssRNA	50	0.04650	W	Wat	N	1	21	0.025	7.835	Ross 1971
Encephalomyocarditis virus	ssRNA	52	0.04460	W	Wat	N	1	900	0.025	7.835	Rauth 1965
Encephalomyocarditis virus	ssRNA	65	0.03550	W	Wat	Y	1	8	0.025	7.835	Zavadova 1968
Epstein-Barr virus (EBV)	ssDNA	162	0.01420	W	Wat	N	1	15000	-	-	Henderson 1978
Equine Herpes virus	dsDNA	25	0.09210	W	Wat	-	-	-	0.105	145.597	Weiss 1986
EVA (fish virus)	ssRNA	5	0.46050	W	Wat	-	-	-	0.06	12.7	Yoshimizu 2005
EVEX (fish virus)	ssRNA	5	0.46050	W	Wat	-	-	-	0.06	11	Yoshimizu 2005
Feline Calicivirus (FeCV)	ssRNA	434	0.00530	W	Wat	N	2	1300	0.034	7.683	Nuanualsuwan 2002
Feline Calicivirus (FeCV)	ssRNA	80	0.02880	W	Wat	N	1	200	0.034	7.683	Thurston-Enriquez 2003
Feline Calicivirus (FeCV)	ssRNA	40	0.05760	W	Wat	N	1	800	0.034	7.683	deRodaHusman 2004
Feline Calicivirus (FeCV)	ssRNA	44	0.05270	W	Wat	N	1	140	0.034	7.683	Tree 2005
Friend Murine Leukemia v.	ssRNA	320	0.00720	W	Wat	N	1	1200	0.094	8.323	Yoshikura 1971
Frog virus 3	dsDNA	25	0.09210	W	Wat	N	1	25	0.167	105.903	Martin 1982
Hepatitis A virus	dsDNA	40	0.05760	W	Wat	N	1	150	0.027	7.478	Battigelli 1993
Hepatitis A virus	dsDNA	45	0.05120	W	Wat	N	1	180	0.027	7.478	Wang 2004
Hepatitis A virus	dsDNA	50	0.04610	W	Wat	-	-		0.027	7.478	Weidenmann 1993
Hepatitis A virus	dsDNA	92	0.02500	W	Wat	N	1	368	0.027	7.478	Wang 1995
Hepatitis A virus	dsDNA	98	0.02340	W	Wat	-	-	-	0.027	7.478	Wilson 1992
Hepatitis A virus	dsDNA	307	0.00750	W	Wat	N	2	1300	0.027	7.478	Nuanualsuwan 2002
Herpes simplex virus (HRE)	dsDNA	40	0.05760	W	Wat	N	1	80	0.18	152.261	Powell 1959
Herpes simplex virus Type 1	dsDNA	71	0.03260	W	Wat	N	2	450	0.184	152.261	Bockstahler 1976
Herpes simplex virus Type 1	dsDNA	110	0.02090	W	Wat	N	2	200	0.184	152.261	Selsky 1978
Herpes simplex virus Type 1	dsDNA	25	0.09330	W	Wat	N	2	300	0.184	152.261	Lytle 1971
Herpes Simplex virus Type 1	dsDNA	35	0.06540	W	Wat	N	2	19	0.184	152.261	Ross 1971
Herpes Simplex virus Type 1	dsDNA	21	0.11050	W	Wat	N	2	40	0.184	152.261	Albrecht 1974
Herpes Simplex virus Type 1	dsDNA	41	0.05680	W	Wat	N	1	20	0.184	152.261	Henderson 1978
Herpes Simplex virus Type 2	dsDNA	40	0.05756	W	Wat	-	-	-	0.173	154.746	Wolff 1973
Herpes Simplex virus Type 2	dsDNA	41	0.05650	W	Wat	N	2	19	0.173	154.746	Ross 1971
Herpes Simplex virus Type 2	dsDNA	75	0.03070	W	Wat	N	2	80	0.173	154.746	Ryan 1986
Herpes Simplex virus Type 2	dsDNA	20	0.11800	W	Wat	N	2	40	0.173	154.746	Albrecht 1974
HIV-1	ssRNA	280	0.00822	W	Wat	Y	1	400	0.125	9.181	Yoshikura 1989
HIRRV (fish virus)	ssRNA	5	0.46050	W	Wat	-	-	-	0.06	11	Yoshimizu 2005
HP1c1 phage	dsDNA	40	0.05760	W	Wat	N	2	180	0.062	32.35	Setlow 1972
HTLV-1	ssRNA	20	0.11510	W	Wat	N	1	35	0.102	8.507	Shimizu 2004
Human Cytomegalovirus	dsDNA	658	0.00350	S	-	Y	1	1950	0.1	-	Hirai 1977
Human Cytomegalovirus	dsDNA	50	0.04605	S	-	N	2	-	0.1	-	Albrecht 1974
Influenza A virus	ssRNA	19	0.11900	Air	68	N	1	68	0.098	13.498	Jensen 1964
Influenza A virus	ssRNA	20	0.11700	W	Wat	N	1	9	0.098	13.498	Ross 1971
Influenza A virus	ssRNA	48	0.04800	W	Wat	Y	1	-	0.098	13.498	Hollaender 1944
Influenza A virus	ssRNA	17	0.13810	W	Wat	N	1	14	0.098	13.498	Abraham 1979
IHNV (fish virus)	ssRNA	5	0.46050	W	Wat	-	-	-	0.09	12	Yoshimizu 2005
IHNV (fish virus)	ssRNA	7	0.34500	W	Wat	-	-	-	0.09	12	Sako 1985
IPNV (fish virus)	dsRNA	397	0.00580	W	Wat	N	2	2000	0.06	6	Oye 2001
IPNV (fish virus)	dsRNA	407	0.00566	W	Wat	N	2	1220	0.06	6	Liltved 1995
IPNV (fish virus)	dsRNA	501	0.00460	W	Wat	-	-	-	0.06	6	Yoshimizu 2005
IPNV (fish virus)	dsRNA	626	0.00368	W	Wat	-	-	1500	0.06	6	Ahne 1982
IPNV (fish virus)	dsRNA	583	0.00395	W	Wat	-	-	2000	0.06	6	Sako 1985
Iridovirus (Bohle) (fish virus)	dsDNA	83	0.02760	W	Wat	-	-	-	-	-	Miocevic 1993
ISAV (fish virus)	ssRNA	11	0.20900	W	Wat	N	2	70	-	12.7	Oye 2001
ISAV (fish virus)	ssRNA	26	0.08970	W	Wat	-	-	-	-	12.7	Liltved 1995
JF-LCDV (fish virus)	dsDNA	5	0.46050	W	Wat	-	-	-	0.14	102.6	Yoshimizu 2005
Kemerovo (R-10 strain)	dsRNA	230	0.01000	W	Wat	N	1	900	0.075	-	Zavadova 1975
Kilham Rat Virus (parvovirus)	ssDNA	30	0.07650	W	Wat	-	-	-	0.022	5	Proctor 1972

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Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	Sh	St	UL J/m^2	Dia. µm	Base Pairs kb	Source (see Chapter 4 Refs)
Lipovnik (Lip-91 strain)	dsRNA	299	0.00770	W	Wat	N	2	200	0.075	-	Zavadova 1975
LLE46 (SV/Adeno hybrid)	dsDNA	606	0.00380	W	Wat	N	1	2376	-	-	Defendi 1967
Measles virus	ssRNA	22	0.10510	W	Wat	N	1	48	0.329	15.894	DiStefano 1976
Mengovirus	dsRNA	162	0.01420	W	Wat	N	2	70	-	6.1	Miller 1974
Minute Virus of Mice (MVM)	ssDNA	28	0.08200	W	Wat	N	1	8	0.022	5.081	Vos 1981
Minute Virus of Mice (MVM)	ssDNA	17	0.13500	W	Wat	N	1	70	0.022	5.081	Rommelaere 1981
Murine Cytomegalovirus	dsDNA	46	0.05000	W	Wat	N	2	116	0.104	230.278	Shanley 1982
Moloney Murine Leukemia v.	ssRNA	115	0.02000	W	Wat	N	1	330	0.094	8.332	Nomura 1972
Moloney Murine Leukemia v.	ssRNA	370	0.00622	W	Wat	N	1	1000	0.094	8.332	Guillemain 1981
Moloney Murine Leukemia v.	ssRNA	280	0.00822	W	Wat	-			0.094	8.332	Yoshikura 1989
Murine Norovirus (MNV)	ssRNA	76	0.03040	W	Wat	N	1	250	0.032	7.382	Lee 2008
Murine sarcoma virus	ssRNA	237	0.00970	W	Wat	N	1	432	0.12	5.833	Nomura 1972
Murine sarcoma virus	ssRNA	144	0.01600	W	Wat	N	1	74	0.12	5.833	Kelloff 1970
Murine sarcoma virus	ssRNA	299	0.00770	W	Wat	N	1	300	0.12	5.833	Yoshikura 1971
Mycobacteriophage D29	dsDNA	16	0.14300	W	Wat	N	2	120	0.065	49.136	David 1973
Mycobacteriophage D29	dsDNA	324	0.00710	W	Wat	N	2	950	0.065	49.136	Sellers 1970
Mycobacteriophage D29A	dsDNA	268	0.00860	W	Wat	N	2	950	0.065	49.136	Sellers 1970
Mycobacteriophage D32	dsDNA	354	0.00650	W	Wat	N	1	950	-	-	Sellers 1970
Mycobacteriophage D4	dsDNA	245	0.00940	W	Wat	N	1	950	-	-	Sellers 1970
Mycoplasmavirus MVL2	dsDNA	154	0.01500	W	Wat	Y	1	600	-	-	Das 1977
Mycoplasmavirus MVL51	ssDNA	79	0.02900	W	Wat	Y	1	250	-	-	Das 1977
Newcastle Disease Virus	ssRNA	8	0.27600	W	Wat	-	-	-	0.212	15.186	vonBrodorotti 1982
Newcastle Disease Virus	ssRNA	45	0.05110	W	Wat	N	1	90	0.212	15.186	Levinson 1966
Newcastle Disease Virus	ssRNA	16	0.14400	S	-	N	1	50	0.212	15.186	Rubin 1959
OMV (fish virus)	ssRNA	5	0.46050	W	Wat	-	-	-	0.06	-	Yoshimizu 2005
Parvovirus H-1	ssDNA	25	0.09200	W	Wat	N	1	55	0.022	6.194	Cornellis 1982
PFRV (fish virus)	ssRNA	5	0.46050	W	Wat	-	-	-	0.06	11	Yoshimizu 2005
phage GA	ssRNA	200	0.01150	W	Wat	N	1	1500	-	-	Simonet 2006
phage phi 6	dsRNA	5	0.43000	Air	Lo RH	N	1	12	-	-	Tseng 2005
phage phi 6	dsRNA	7	0.31000	Air	Hi RH	N	1	12	-	-	Tseng 2005
phage B40-8 (B. fragilis)	dsDNA	67	0.03450	W	Wat	Y	1	400	-	-	Sommer 2001
phage B40-8 (B. fragilis)	dsDNA	86	0.02690	W	Wat	N	1	280	-	-	Sommer 1998
Poliovirus	dsRNA	44	0.05230	S	-	N	1	220	0.0248	7.44	Ma 1994
Poliovirus type 1	dsRNA	41	0.05620	S	-	N	1	-	0.0248	7.44	Meng 1996
Poliovirus	dsRNA	71	0.03250	W	Wat	Y	1	216	0.0248	7.44	Helentjaris 1977
Poliovirus	dsRNA	75	0.03070	W	Wat	N	1	30	0.0248	7.44	Shin 2005
Poliovirus	dsRNA	95	0.02420	W	Wat	N	1	54	0.0248	7.44	Bishop 1967
Poliovirus	dsRNA	52	0.04460	W	Wat	N	1	900	0.0248	7.44	Dulbecco 1955
Poliovirus type 1	dsRNA	67	0.03450	W	Wat	N	2	300	0.0248	7.44	Chang 1985
Poliovirus type 1	dsRNA	72	0.03200	W	Wat	-	-	-	0.0248	7.44	Wilson 1992
Poliovirus type 1	dsRNA	96	0.02400	W	Wat	N	1	480	0.0248	7.44	Wetz 1982
Poliovirus type 1	dsRNA	100	0.02300	W	Wat	-	-	-	0.0248	7.44	Thompson 2003
Poliovirus type 1	dsRNA	125	0.01840	W	Wat	-	-	-	0.0248	7.44	Oppenheimer 1997
Poliovirus type 1	dsRNA	224	0.01030	W	Wat	N	1	1165	0.0248	7.44	Nuanualsuw an 2003
Poliovirus type 1	dsRNA	240	0.00960	W	Wat	N	1	1300	0.0248	7.44	Nuanualsuw an 2002
Poliovirus type 1	dsRNA	111	0.02080	W	Wat	N	1	348	0.0248	7.44	Hill 1970
Poliovirus type 1	dsRNA	77	0.03000	W	Wat	N	1	-	0.0248	7.44	Harris 1987
Poliovirus type 1	dsRNA	80	0.02878	W	Wat	N	1	400	0.0248	7.44	Gerba 2002
Poliovirus type 1	dsRNA	83	0.02760	W	Wat	N	1	1500	0.0248	7.44	Simonet 2006
Poliovirus type 1	dsRNA	57	0.04010	W	Wat	N	1	270	0.0248	7.44	Tree 2005
Poliovirus type 2	dsRNA	121	0.01910	W	Wat	N	1	348	0.0248	7.44	Hill 1970
Poliovirus type 3	dsRNA	103	0.02240	W	Wat	N	1	348	0.0248	7.44	Hill 1970
Polyomavirus	dsDNA	480	0.00480	W	Wat	N	1	240	0.0424	5	vander Eb 1967
Polyomavirus	dsDNA	640	0.00360	W	Wat	N	1	2376	0.0424	5	Defendi 1967
Polyomavirus	dsDNA	696	0.00331	W	Wat	N	1	900	0.0424	5	Rauth 1965
Polyomavirus	dsDNA	501	0.00460	W	Wat	-	-	-	0.0424	5	Latarjet 1967
Polyomavirus (ssDNA)	ssDNA	120	0.01920	W	Wat	N	2	240	0.045	5	vander Eb 1967
Porcine Parvovirus (PPV)	ssDNA	23	0.10230	W	Wat	N	1	90	0.021	6.194	Wang 2004
Pseudorabies (PRV)	dsDNA	34	0.06760	W	Wat	N	2	15	0.194	-	Ross 1971
Rabies virus (env)	ssRNA	10	0.21930	W	Wat	-	-	-	0.07	11.932	Weiss 1986
Rauscher Murine Leukemia v.	ssRNA	157	0.01470	W	Wat	N	1	74	0.094	8.282	Kelloff 1970
Rauscher Murine Leukemia v.	ssRNA	480	0.00480	W	Wat	N	1	200	0.094	8.282	Lovinger 1975
Rauscher Murine Leukemia v.	ssRNA	959	0.00240	S	-	N	2	4800	0.094	8.282	Stull 1976

UV Rate Constants for Viruses

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	Sh	St	UL J/m^2	Dia. µm	Base Pairs kb	Source (see Chapter 4 Refs)
Reovirus	dsRNA	175	0.01316	W	Wat	N	1	348	0.075	11	Hill 1970
Reovirus	dsRNA	186	0.01240	W	Wat	N	1	740	0.075	11	Wang 2004
Reovirus	dsRNA	69	0.03358	W	Wat	-	-	-	0.075	11	vonBrodorotti 1982
Reovirus	dsRNA	245	0.00940	W	Wat	N	2	990	0.075	11	Shaw 1973
Reovirus	dsRNA	121	0.01910	W	Wat	N	1	900	0.075	11	Rauth 1965
Reovirus	dsRNA	270	0.00853	W	Wat	N	2	1080	0.075	11	McClain 1966
Reovirus	dsRNA	174	0.01320	W	Wat	N	1	348	0.075	11	Hill 1970
Reovirus type 1	dsRNA	153	0.01508	W	Wat	N	1	-	0.075	11	Harris 1987
Reovirus 3	dsRNA	334	0.00690	W	Wat	N	2	300	0.075	11	Zavadova 1975
Rotavirus	dsRNA	200	0.01150	W	Wat	N	2	200	0.07	-	Caballero 2004
Rotavirus SA11	dsRNA	89	0.02600	W	Wat	-	-	-	0.07	-	Wilson 1992
Rotavirus SA11	dsRNA	75	0.03070	W	Wat	N	1	750	0.07	-	Meng 1987
Rotavirus SA11	dsRNA	105	0.02190	W	Wat	N	2	250	0.07	-	Battigelli 1993
Rotavirus SA11	dsRNA	100	0.02300	W	Wat	N	1	350	0.07	-	Chang 1985
Rotavirus SA11	dsRNA	84	0.02740	W	Wat	N	1	380	0.07	-	Sommer 1989
Rous Sarcoma virus (RSV)	ssRNA	720	0.00320	W	Wat	N	1	36	0.127	9.392	Levinson 1966
Rous Sarcoma virus (RSV)	ssRNA	240	0.00960	W	Wat	-	-	-	0.127	9.392	Golde 1961
Rous Sarcoma virus (RSV)	ssRNA	200	0.01150	S	-	N	1	700	0.127	9.392	Rubin 1959
SBNN (fish virus)	ssRNA	698	0.00330	W	Wat	Y	2	2640	-	-	Frerichs 2000
Semliki forest virus	ssRNA	25	0.09210	W	Wat	-	-	-	0.061	11.442	Weiss 1986
Simian virus 40	dsDNA	2503	0.00092	W	Wat	N	1	2500	0.045	5.243	Bourre 1989
Simian virus 40	dsDNA	1599	0.00144	W	Wat	N	2	8000	0.045	5.243	Seemayer 1973
Simian virus 40	dsDNA	1439	0.00160	W	Wat	N	1	1500	0.045	5.243	Cornellis 1981
Simian virus 40	dsDNA	1245	0.00185	W	Wat	-	-	-	0.045	5.243	Bockstahler 1977
Simian virus 40	dsDNA	886	0.00260	W	Wat	N	1	2376	0.045	5.243	Defendi 1967
Simian virus 40	dsDNA	650	0.00354	W	Wat	N	1	1300	0.045	5.243	Sarasin 1978
Simian virus 40	dsDNA	443	0.00520	W	Wat	-	-	240	0.045	5.243	Aaronson 1970
Simian virus 40	dsDNA	23	0.10040	W	Wat	N	1	55	0.045	5.243	Cornellis 1982
Simian virus 40	dsDNA	17	0.13160	W	Wat	N	1	70	0.045	5.243	Wang 2004
Sindbis virus	ssRNA	22	0.10400	Air	62	N	1	68	0.075	11.703	Jensen 1964
Sindbis virus	ssRNA	60	0.03864	W	Wat	-	-	-	0.075	11.703	vonBrodorotti 1982
Sindbis virus	ssRNA	113	0.02030	W	Wat	N	1	400	0.075	11.703	Wang 2004
Sindbis virus	ssRNA	50	0.04610	W	Wat	N	1	200	0.075	11.703	Zavadova 1975
S. aureus phage	dsDNA	82	0.02800	S	-	N	1	30	-	-	Gates 1934
S. aureus phage	dsDNA	77	0.03000	S	-	N	1	4	-	-	Sturm 1932
S. aureus phage A994	dsDNA	65	0.03542	W	Wat	-	-	-	-	-	Sommer 1989
SVCV (fish virus)	ssRNA	10	0.46050	W	Wat	-	-	-	0.06	11.1	Yoshimizu 2005
Vaccinia virus	dsDNA	1	2.54000	Air	60	N	1	3	0.307	195.815	McDevitt 2007
Vaccinia virus	dsDNA	15	0.15300	Air	65	N	1	68	0.307	195.815	Jensen 1964
Vaccinia virus	dsDNA	7	0.34900	W	Wat	N	1	10	0.307	195.815	Galasso 1965
Vaccinia virus	dsDNA	14	0.16450	W	Wat	N	1	30	0.307	195.815	Bossart 1978
Vaccinia virus	dsDNA	14	0.16040	W	Wat	N	1	6	0.307	195.815	Ross 1971
Vaccinia virus	dsDNA	18	0.12792	W	Wat	N	1	20	0.307	195.815	Klein 1994
Vaccinia virus	dsDNA	22	0.10500	W	Wat	N	2	8	0.307	195.815	Zavadova 1971
Vaccinia virus	dsDNA	28	0.08290	W	Wat	N	1	900	0.307	195.815	Rauth 1965
Vaccinia virus	dsDNA	715	0.00322	W	Wat	N	2	70000	0.307	195.815	Davidovich 1991
Vaccinia virus	dsDNA	677	0.00340	W	Wat	N	1	4300	0.307	195.815	Collier 1955
VEE	ssRNA	55	0.04190	W	Wat	-	-	-	0.065	11.444	Smirnov 1992
Vesicular Stomatitis virus	ssRNA	13	0.18060	W	Wat	N	1	900	0.104	11.161	Rauth 1965
Vesicular Stomatitis virus	ssRNA	12	0.19000	W	Wat	-	-	-	0.104	11.161	Helentjaris 1977
Vesicular Stomatitis virus	ssRNA	100	0.02300	W	Wat	N	1	10	0.104	11.161	Bay 1979
Vesicular Stomatitis virus	ssRNA	6	0.38400	W	Wat	N	1	-	0.104	11.161	Shimizu 2004
VHSV (fish virus)	ssRNA	3	0.87400	W	Wat	-	-	20	0.07	11.158	Oye 2001
WEE	ssRNA	54	0.04300	W	Wat	N	1	83	0.07	11.484	Dubinin 1975

NOTES for Appendices A, B & C:

Type: Sp = Spore, Veg = Vegetative, VegY = Vegetative yeast

D_{90}: UV Dose for 90% inactivation (10% survival)

UVGI k: UV rate constant at the given D_{90} (and below the UL)

UL: Upper Limit within which D_{90} and rate constants are applicable

Media: A = Air, S = Surface, W = Water RH = Relative Humidity

Sh = Shoulder in decay curve (shoulder is ignored for k and D_{90} values)

St = Number of stages in decay curve (k & D_{90} only applies to first stage)

Dia.: Logmean diameter in microns, including envelope for viruses if any

MP: Medium Pressure UV lamp, LP: Low Pressure UV lamp

UV Rate Constants for Fungi and Other Microbes

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	Sh	St	UL J/m^2	Dia. µm	Base Pairs kb	Source (see Chapter 4 Refs)
Aspergillus amstelodami	Sp	700	0.00329	W	Wat	-	-	-	3.354	35900	Jepson 1973
Aspergillus amstelodami	Sp	258	0.00892	S	-	N	1	336	3.354	35900	Luckiesh 1949
Aspergillus amstelodami	Sp	669	0.00344	Air	67	N	2	870	3.354	35900	Luckiesh 1949
Aspergillus flavus	Sp	349	0.00660	S	-	N	1	35	4.24	35900	Green 2004
Aspergillus flavus	Sp	600	0.00384	-	-	-	-	-	4.24	35900	Nagy 1964
Aspergillus flavus	Sp	853	0.00270	W	Wat	N	1	13932	4.24	35900	Begum 2009
Aspergillus fumigatus	Sp	535	0.00430	S	-	N	1	54	4.24	35900	Green 2004
Aspergillus fumigatus	Veg	560	0.00411	S	-	-	-	560	24.5	35900	Chick 1963
Aspergillus fumigatus	Sp	2240	0.00103	S	-	-	-	2240	2.64	35900	Chick 1963
Aspergillus glaucus	Sp	440	0.00523	-	-	-	-	-	3.354	35900	Nagy 1964
Aspergillus niger	Sp	1771	0.00130	S	Lo RH	Y	2	1600	3.354	35900	Zahl 1939
Aspergillus niger	Sp	1439	0.00160	S	-	-	2	3384	3.354	35900	Fulton 1929
Aspergillus niger	Veg	4480	0.00051	S	-	-	-	4480	3.354	35900	Chick 1963
Aspergillus niger	Sp	1000	0.00230	W	Wat	-	-	-	3.354	35900	Jepson 1973
Aspergillus niger	Sp	315	0.00350	S	-	Y	2	18	3.354	35900	Kowalski 2001
Aspergillus niger	Sp	1387	0.00166	S	-	N	1	1800	3.354	35900	Luckiesh 1949
Aspergillus niger	Sp	750	0.00386	S	-	-	-	3000	3.354	35900	Gritz 1990
Aspergillus niger	Sp	4480	0.00051	S	-	-	-	4480	3.354	35900	Chick 1963
Aspergillus niger	Sp	3984	0.00058	Air	55	N	2	5400	3.354	35900	Luckiesh 1949
Aspergillus niger	Sp	1320	0.00174	-	-	-	-	-	3.354	35900	Nagy 1964
Aspergillus niger	Sp	1681	0.00137	W	Wat	N	2	9288	3.354	35900	Begum 2009
Aspergillus versicolor	Sp	384	0.00600	Air	85	N	1	32	3.354	35900	vanOsdell 2002
Aspergillus versicolor	Sp	768	0.00300	Air	55	N	1	32	3.354	35900	vanOsdell 2002
Aspergillus versicolor	Sp	139	0.01660	Air	50	N	1	32	3.354	35900	vanOsdell 2002
Aspergillus versicolor	Veg	96	0.02400	Air	(Lo RH)	N	1	940	3.354	35900	Nakamura 1987
Blastomyces dermatitidis	VegY	140	0.01645	S	-	-	-	140	11.000	23000	Chick 1963
Botrytis cinerea	Sp	250	0.00920	S	-	N	1	1000	11.180	42660	Marquenie 2002
Candida albicans	VegY	230	0.01100	W	Wat	N	2	440	4.899	20000	Dolman 1989
Candida albicans	VegY	447	0.00515	W	Wat	N	1	453	4.899	20000	Abshire 1981
Candida albicans	VegY	750	0.00407	S	-	-	-	3000	4.899	20000	Gritz 1990
Candida albicans	VegY	280	0.00822	S	-	-	-	280	4.899	20000	Chick 1963
Candida parapsilosis	VegY	98	0.02360	W	Wat	N	1	390	-	-	Severin 1983
Cladosporium herbarum	Sp	500	0.04605	W	Wat	-	-	-	8.062	36000	Jepson 1973
Cladosporium herbarum	Sp	189	0.01220	S	-	N	1	246	8.062	36000	Luckiesh 1949
Cladosporium herbarum	Sp	622	0.00370	Air	53	N	2	810	8.062	36000	Luckiesh 1949
Cladosporium trichoides	Veg	560	0.00411	S	-	-	-	560	8.062	36000	Chick 1963
Cladosporium trichoides	Sp	1120	0.00206	S	-	-	-	1120	8.062	36000	Chick 1963
C. sphaerospermum	Sp	1439	0.00210	Air	50	N	1	32	8.062	36000	vanOsdell 2002
Cladosporium wernecki	Sp	4480	0.00051	S	-	-	-	4480	8.062	36000	Chick 1963
Cladosporium wernecki	Veg	560	0.00411	S	-	-	-	560	8.062	36000	Chick 1963
Cryptococcus neoformans	Sp	138	0.01670	S	-	N	1	400	4.899	23000	Wang 1994
Cryptococcus neoformans	VegY	280	0.00822	S	-	-	-	280	4.899	23000	Chick 1963
Curvularia lunata	Veg	560	0.00411	S	-	-	-	560	17.100	29700	Chick 1963
Eurotium rubrum	Sp	434	0.00531	W	Wat	N	2	4644	5.612	-	Begum 2009
Fusarium oxysporum	Sp	260	0.01420	W	Wat	Y	2	600	11.225	43000	Asthana 1992
Fusarium solani	Sp	313	0.00735	W	Wat	N	2	960	11.225	43000	Asthana 1992
Fusarium spp.	Sp	560	0.00411	S	-	-	-	560	11.225	43000	Chick 1963
Fusarium spp.	Veg	1120	0.00206	S	-	-	-	1120	34.300	43000	Chick 1963
Histoplasma capsulatum	Veg	140	0.01645	S	-	-	-	140	2.550	23000	Chick 1963
Monilinia fructigena	Sp	167	0.01380	S	-	N	1	500	10.300	-	Marquenie 2002
Mucor mucedo	Sp	600	0.00384	W	Wat	-	-	-	7.071	39000	Jepson 1973
Mucor mucedo	Sp	180	0.01280	S	-	N	1	234	7.071	39000	Luckiesh 1949
Mucor mucedo	Sp	577	0.00399	Air	63	N	2	750	7.071	39000	Luckiesh 1949
Mucor racemosus	Sp	170	0.01354	-	-	-	-	-	7.071	39000	Nagy 1964
Mucor spp.	Sp	140	0.01645	S	-	-	-	140	7.071	39000	Chick 1963
Mucor spp.	Veg	280	0.00822	S	-	-	-	280	31.600	39000	Chick 1963
Oospora lactis	Sp	28	0.08370	-	-	-	1	110	-	-	Nagy 1964
Penicillium chrysogenum	Sp	400	0.00576	W	Wat	-	-	-	3.262	34000	Jepson 1973
Penicillium chrysogenum	Sp	148	0.01560	S	-	N	1	192	3.262	34000	Luckiesh 1949
Penicillium chrysogenum	Sp	1645	0.00180	Air	50	N	1	32	3.262	34000	vanOsdell 2002
Penicillium chrysogenum	Sp	531	0.00434	Air	41	N	2	690	3.262	34000	Luckiesh 1949
Penicillium corylophilium	Sp	381	0.00604	W	Wat	N	2	4644	3.262	34000	Begum 2009
Penicillium digitatum	Sp	321	0.00718	W	Wat	Y	1	960	3.262	34000	Asthana 1992

UV Rate Constants for Fungi and Other Microbes

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	Sh	St	UL J/m^2	Dia. μm	Base Pairs kb	Source (see Chapter 4 Refs)
Penicillium digitatum	Sp	440	0.00523	-	-	-	-	-	3.262	34000	Nagy 1964
Penicillium expansum	Sp	130	0.01771	-	-	-	-	-	3.262	34000	Nagy 1964
Penicillium italicum	Sp	321	0.01140	W	Wat	Y	2	590	3.262	34000	Asthana 1992
Penicillium roquefortii	Sp	130	0.01771	-	-	-	-	-	3.262	34000	Nagy 1964
Penicillium spp.	Sp	2240	0.00103	S	-	-	-	2240	3.262	34000	Chick 1963
Penicillium spp.	Veg	280	0.00822	S	-	-	-	280	8.800	34000	Chick 1963
Rhizopus nigricans	Sp	3000	0.00077	W	Wat	-	-	-	6.928	54178	Jepson 1973
Rhizopus nigricans	Sp	267	0.00861	Air	62	N	2	348	6.928	54178	Luckiesh 1949
Rhizopus nigricans	Sp	1110	0.00207	-	-	-	-	-	6.928	54178	Nagy 1964
Rhizopus nigricans	Sp	173	0.01330	S	-	Y	2	200	6.928	54178	Kowalski 2001
Rhizopus oryzae	Sp	4480	0.00051	S	-	-	-	4480	6.928	-	Chick 1963
Rhodotorula spp.	VegY	1120	0.00206	S	-	-	-	1120	5.900	-	Chick 1963
Saccharomyces spp.	VegY	44	0.05230	-	-	-	1	176	-	-	Nagy 1964
Saccharomyces ellipsoideus	VegY	33	0.06980	-	-	-	1	132	-	-	Nagy 1964
Scopulariopsis brevicaulis	Sp	650	0.01840	W	Wat	-	-	-	5.916	-	Jepson 1973
Scopulariopsis brevicaulis	Sp	226	0.01020	S	-	N	1	294	5.916	-	Luckiesh 1949
Scopulariopsis brevicaulis	Sp	2890	0.00344	Air	79	N	2	870	5.916	-	Luckiesh 1949
Sporotrichum schenkii	VegY	280	0.00822	S	-	-	-	280	5.500	-	Chick 1963
Stachybotrys chartarum	Sp	5575	0.00041	S	-	N	1	1440	5.623	-	Green 2005
Torula bergeri	Veg	4480	0.00051	S	-	-	-	4480	40	-	Chick 1963
Torula sphaerica	VegY	23	0.09986	Air	65	N	2	30	40	-	Luckiesh 1949
Torula sphaerica	VegY	78	0.02940	S	-	N	1	102	40	-	Luckiesh 1949
Trichophyton rubrum	Veg	560	0.00411	S	-	-	-	560	4.899	-	Chick 1963
Trichophyton rubrum	Sp	560	0.00411	S	-	-	-	560	4.899	-	Chick 1963
Ustilago zeae	VegY	1120	0.00206	S	-	-	-	1120	5.916	20500	Chick 1963
Ustilago zeae	Sp	35	0.06580	-	-	-	-	-	5.916	20500	Sussman 1966
Yeast	VegY	40	0.05756	W	Wat	-	-	-	-	-	Jepson 1973
Yeast (Brewer's)	VegY	100	0.02303	W	Wat	-	-	-	-	-	Jepson 1973
Protozoa and Other Microbes											
Acanthameoba	Rhizopod	999	0.02100	W	Wat	-	-	-	-	-	Maya 2003
Acanthameoba castellani	Rhizopod	992	0.00232	S	-	-	-	3000	-	-	Gritz 1990
Algae	Algae	1000	0.00230	-	-	-	-	-	-	-	Summer 1962
Algae, blue-green	Algae	450	0.00512	-	-	-	-	-	-	-	Jepson 1973
Cryptosporidium hominis	Protoz	30	0.07800	-	-	-	-	-	-	-	Johnson 2005
Cryptosporidium parvum	Protoz	7	0.31400	W	Wat	N	1	20	3	-	Oguma 2001
Cryptosporidium parvum	Protoz	20	0.11500	W	Wat	-	-	30	3	-	Zimmer 2003
Cryptosporidium parvum	Protoz	10	0.23030	W	Wat	N	1	30	3	-	Shin 2001
Cryptosporidium parvum	Protoz	50	0.04605	W	Wat	N	2	100	3	-	Craik 2001
Cryptosporidium parvum	Protoz	10	0.23220	W	Wat	N	1	40	3	-	Bukhari 2004
Cryptosporidium parvum	Protoz	5	0.45830	W	Wat	N	1	22	3	-	Morita 2002
Encephalitozoon intestinalis	Protoz	29	0.07830	W	Wat	N	2	50	-	-	``````
Encephalitozoon intestinalis	Protoz	15	0.15350	W	Wat	N	-	-	-	-	Huffman 2002
Encephalitozoon cuniculi	Protoz	43	0.05310	W	Wat	N	1	130	-	-	Marshall 2003
Encephalitozoon hellem	Protoz	80	0.02880	W	Wat	N	2	120	-	-	Marshall 2003
Giardia lamblia cysts	Protoz	50	0.04610	W	Wat	-	-	20	-	-	Campbell 2002
Giardia lamblia cysts	Protoz	3	0.92100	W	Wat	N	1	10	-	-	Shin 2005
Giardia lamblia cysts	Protoz	20	0.11500	W	Wat	N	1	40	-	-	Li 2007
Giardia muris cysts	Protoz	10	0.23020	W	Wat	N	2	10	-	-	Craik 2001
Giardia muris cysts	Protoz	7	0.34130	W	Wat	N	1	23	-	-	Hayes 2000
Protozoa	Protoz	80	0.02878	-	-	-	-	-	-	-	Jepson 1973
Protozoa	Protoz	240	0.00959	-	-	-	-	-	-	-	Summer 1962
Prions (scrapie)	Prion	24315	0.00009	-	-	-	-	-	-	-	Bellinger-Kawahara 1987
Prions (scrapie)	Prion	55618	0.00004	-	-	-	-	-	-	-	Alper 1967

Appendix B

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ORIGINAL ARTICLE

Room Decontamination with UV Radiation

William A. Rutala, PhD, MPH; Maria F. Gergen, MT (ASCP); David J. Weber, MD, MPH

OBJECTIVE. To determine the effectiveness of a UV-C–emitting device to eliminate clinically important nosocomial pathogens in a contaminated hospital room.

METHODS. This study was carried out in a standard but empty hospital room (phase 1) and in a room previously occupied by a patient with methicillin-resistant *Staphylococcus aureus* (MRSA) or vancomycin-resistant *Enterococcus* (VRE) infection (phase 2) in an acute care tertiary hospital in North Carolina from January 21 through September 21, 2009. During phase 1, 8 × 8 cm Formica sheets contaminated with approximately 10^4–10^5 organisms of MRSA, VRE, multidrug-resistant (MDR) *Acinetobacter baumannii,* or *Clostridium difficile* spores were placed in a hospital room, both in direct line of sight of the UV-C device and behind objects. After timed exposure, the presence of the microbes was assessed. During phase 2, specific sites in rooms that had housed patients with MRSA or VRE infection were sampled before and after UV-C irradiation. After timed exposure, the presence of MRSA and VRE and total colony counts were assessed.

RESULTS. In our test room, the effectiveness of UV-C radiation in reducing the counts of vegetative bacteria on surfaces was more than 99.9% within 15 minutes, and the reduction in *C. difficile* spores was 99.8% within 50 minutes. In rooms occupied by patients with MRSA, UV-C irradiation of approximately 15 minutes duration resulted in a decrease in total CFUs per plate (mean, 384 CFUs vs 19 CFUs; $P < .001$), in the number of samples positive for MRSA (81 [20.3%] of 400 plates vs 2 [0.5%] of 400 plates; $P < .001$), and in MRSA counts per MRSA-positive plate (mean, 37 CFUs vs 2 CFUs; $P < .001$).

CONCLUSIONS. This UV-C device was effective in eliminating vegetative bacteria on contaminated surfaces both in the line of sight and behind objects within approximately 15 minutes and in eliminating *C. difficile* spores within 50 minutes.

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Surface disinfection of noncritical surfaces and equipment is normally performed by manually applying a liquid disinfectant to the surface with a cloth, wipe, or mop. Recent studies have identified substantial opportunities in hospitals to improve the cleaning of frequently touched objects in the patient's immediate environment.[1-3] For example, of 20,646 standardized environmental surfaces (14 types of objects), only 9,910 (48%) were cleaned at terminal room cleaning.[3] Epidemiologic studies have shown that patients hospitalized in rooms previously occupied by individuals infected or colonized with methicillin-resistant *Staphylococcus aureus* (MRSA),[4] vancomycin-resistant *Enterococcus* (VRE),[5] or *Clostridium difficile*[6] are at significant risk of acquiring these organisms from contaminated environmental surfaces. These data have inspired the development of room decontamination devices that avoid the problems associated with manual disinfection.[7]

Devices using UV-C light (wavelength, 254 nm) have also been proposed for room decontamination. One UV-C device uses an array of UV sensors, which determines and targets shadowed areas to deliver a measured dose of UV energy that destroys microorganisms. This unit is fully automated and activated by a hand-held remote control, and the room ventilation does not need to be modified. It measures UV light reflected from the walls, ceiling, floors, or items in the room and calculates the time required to deliver the programmed lethal dose for pathogens.[8] After decontamination, it powers down and an audible alarm notifies the operator. The purpose of this article is to summarize our evaluation of the ability of this device to decontaminate rooms that were experimentally or naturally contaminated with epidemiologically important pathogens, such as MRSA, VRE, a multidrug-resistant (MDR) strain of *Acinetobacter baumannii,* and *C. difficile* spores.

METHODS

The study was performed at University of North Carolina Health Care, an acute care tertiary hospital in Chapel Hill, North Carolina, during the period January 21 through September 21, 2009.

Phase 1: Clinical Translational Research Center

A single UV-C device was investigated (Tru-D; Lumalier Corporation). This device delivers a reflected dose of 36,000 μWs/

From Hospital Epidemiology, University of North Carolina Health Care (all authors), and the Division of Infectious Diseases, University of North Carolina School of Medicine (W.A.R., D.J.W.), Chapel Hill, North Carolina.

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cm^2 (ie, when Tru-D powers down, the sensor facing the least reflected area of the room has received a reflective dose of 36,000 $\mu Ws/cm^2$) for *C. difficile* spores and 12,000 $\mu Ws/cm^2$ for vegetative bacteria. Phase 1 testing was performed in a patient room (10.9 m^2 main room with 1.2 m^2 bathroom) in the Clinical Translational Research Center. This testing was performed using Formica sheets (approximately 8 × 8 cm) on which a template of a Rodac plate had been drawn. The vegetative bacteria were grown on sheep's blood agar and serial dilutions made with trypticase soy broth (Remel). The *C. difficile* spore preparation was stored in Dulbecco's modified Eagle's medium (HyClone), and serial dilutions were made with trypticase soy broth. An inoculum of approximately 10^4–10^5 organisms per Rodac template (10 μL of a 10^6–10^7 cell inoculum of the test organism) of the 4 test organisms was spread separately on the Formica sheet by use of a sterile glass hockey loop. The 4 test organisms were *C. difficile* spores (BI strain), a clinical isolate of MRSA (USA300 strain), a VRE strain (ATCC strain 51299), and a clinical isolate of MDR *A. baumannii* (Table 1). After the templates were inoculated, they were left to dry a minimum of 10 minutes at room temperature. Die-off experiments revealed that the VRE, MRSA, and *A. baumannii* had no significant die-off within a 6-hour sampling period (less than 0.27 $\log_{10}$ reduction). The Formica sheets were then placed in 10 locations at least 15 cm from the wall throughout the patient room (ie, far side of the bedside table, facing the wall; side of the chair, facing the wall; top of the overbed table; outside of the bathroom door; top of the toilet seat; back of the head of the bed, facing the wall; floor [right side of bed]; foot of the bed, facing the door; side of the sink, facing the bedside table; and back of the computer, facing the wall). After the Formica pieces were placed on the indicated item or attached to the item with tape, the room was vacated and the UV-C device was remotely activated for the test organism being evaluated (for approximately 15 minutes for vegetative bacteria or for approximately 50 minutes for spores). After decontamination, Rodac plates (Becton Dickinson) containing DE Neutralizing Agar (Becton Dickinson) were used to culture each Formica template. These plates were then incubated as appropriate for the test organism (aerobically at 37°C for 48 hours for bacteria and anaerobically [Anaeropack; Mitsubishi Gas Chemical] at 37°C for 48 hours for *C. difficile*). After incubation, the numbers of colony-forming units (CFUs) of the test organisms on each plate were quantified. The *C. difficile* culture was treated with heat at 56°C for 10 minutes, and the presence and resistance of *C. difficile* spores (and not vegetative bacteria) were verified by exposing the stock preparation to dilute hydrochloric acid as specified in the AOAC International sporicidal activity test.[9] The suspension was then stained to confirm the presence of spores (more than 90% spores).

Phase 2: Rooms of Patients under Contact Precautions

Phase 2 involved the culturing of samples from 10 targeted sites (5 replicates per site) in the rooms of patients who had been placed under contact precautions to prevent transmission of MRSA or VRE (Table 2). The patient rooms evaluated had a mean area of 18.2 m^2 (including bathroom if present), and the mean UV exposure time per room was approximately 17 minutes. The 10 sites evaluated are shown in Table 2 with 5 replicates at each site. The first set of samples were collected (using Rodac plates with DE Neutralizing Agar) after patient discharge, and the second set of samples were collected after UV-C treatment of the room and before environmental services staff conducted standard room decontamination. If a site listed in Table 2 was unavailable, another site was cultured, resulting in samples from 16 different sites being cultured. All plates were incubated at 37°C for 48 hours. After 48 hours, all plates were read quantitatively to determine the total number of CFUs per site. In addition, each plate was evaluated specifically for the organism of interest (eg, MRSA or VRE), and that organism was quantitated.

The Student *t* test (2-tailed) was used to test the hypothesis that there was a significant difference in the presence of bacteria on surfaces treated with UV radiation compared with untreated surfaces (Table 2) or a difference between the effect of direct UV-C and indirect UV-C (Table 1). Surfaces were evaluated on whether the UV-C radiation received was direct

TABLE 1. UV-C Decontamination of Formica Surfaces in Patient Rooms Experimentally Contaminated with Methicillin-Resistant *Staphylococcus aureus* (MRSA), Vancomycin-Resistant *Enterococcus* (VRE), Multidrug-Resistant (MDR) *Acinetobacter baumannii,* and *Clostridium difficile* Spores

		UV-C line of sight						
		Total		Direct		Indirect		
Organism	Inoculum	No. of samples	Decontamination, $\log_{10}$ reduction, mean (95% CI)	No. of samples	Decontamination, $\log_{10}$ reduction, mean (95% CI)	No. of samples	Decontamination, $\log_{10}$ reduction, mean (95% CI)	*P*
MRSA	4.88 $\log_{10}$	50	3.94 (2.54–5.34)	10	4.31 (3.13–5.50)	40	3.85 (2.44–5.25)	.06
VRE	4.40 $\log_{10}$	47	3.46 (2.16–4.81)	15	3.90 (2.99–4.81)	32	3.25 (1.97–4.62)	.003
MDR *A. baumannii*	4.64 $\log_{10}$	47	3.88 (2.59–5.16)	10	4.21 (3.27–5.15)	37	3.79 (2.47–5.10)	.07
C. difficile spores	4.12 $\log_{10}$	45	2.79 (1.20–4.37)	10	4.04 (3.71–4.37)	35	2.43 (1.46–3.40)	<.001

NOTE. Patient rooms had a mean area of 12.1 m^2 including bathroom. CI, confidence interval.

TABLE 2. UV-C Decontamination of Surfaces in 8 Patient Rooms That Had Been Occupied by Patients under Contact Precautions for Methicillin-Resistant *Staphylococcus aureus* (MRSA)

Site	Total CFUs per site, mean		MRSA-positive plates/total plates	
	Before UV-C	After UV-C	Before UV-C	After UV-C
Sink ($n = 8$)	134	11	7/40	0/40
Toilet seat ($n = 6$)	559	9	1/30	0/30
Tray table ($n = 8$)	171	4	1/40	0/40
Bedside rail ($n = 7$)	497	16	7/35	0/35
Chair arm ($n = 12$)	276	11	12/60	0/60
Bathroom floor, in front of toilet ($n = 6$)	940	53	16/30	1/30
Floor near bed ($n = 8$)	967	76	23/40	1/40
Monitor ($n = 4$)	24	2	0/20	0/20
Medical cart ($n = 7$)	351	9	5/35	0/35
Laundry bin top ($n = 5$)	442	8	1/25	0/25
Sink counter ($n = 1$)	12	1	0/5	0/5
Chair seat ($n = 1$)	95	2	1/5	0/5
Blood pressure machine ($n = 1$)	111	8	1/5	0/5
Bedside dresser ($n = 4$)	176	5	1/20	0/20
Floor at foot of bed ($n = 1$)	668	14	4/5	0/5
Floor at sink ($n = 1$)	729	82	1/5	0/5
Total	384	19	81/400	2/400

NOTE. The average MRSA count per MRSA-positive plate was 37 CFUs before UV-C disinfection and 2 CFUs after disinfection. Each sample site was evaluated with use of 5 Rodac plates, so, for example, the $n = 8$ sample before UV-C disinfection at the sink site represents 40 plates (8 rooms × 5 samples at the sink in each room); the CFU count of 134 is the mean of the the count of the 5 plates in the 8 rooms at the sink site (1,070 total CFUs/8 sink sites = 134, which is the average of 5 replicates at the 8 sites). The area of a Rodac plate is approximately 26 cm^2. CFU, colony-forming unit.

or indirect by placing a laser pointer at the location of the UV-C device, following the path of the laser, and determining whether the laser point was visible on the site.

RESULTS

In our test room, the effectiveness of UV-C radiation in reducing the counts of vegetative bacteria on surfaces was more than 99.9% in approximately 15 minutes, and the reduction in *C. difficile* spores was 99.8% within 50 minutes. The total CFU $\log_{10}$ reduction, as well as the $\log_{10}$ reduction after direct and indirect exposures, is shown in Table 1. UV-C radiation was more effective when there was a direct line of sight to the contaminant (MRSA, $P = .06$; VRE, $P = .003$; *A. baumannii,* $P = .07$; *C. difficile,* $P < .001$), but meaningful reduction (mean reduction, 3.3–3.9 $\log_{10}$) did occur when the contaminant was not directly exposed to the UV-C (eg, on the back of the computer or the back of the head of the bed). The UV-C dose delivered, as measured by a portable radiometer placed in the patient room on the bed, was 472 mJ/cm^2 for MRSA, 661 mJ/cm^2 for VRE, 627 mJ/cm^2 for *A. baumannii,* and 2,123 mJ/cm^2 for *C. diffficile* spores.

After treatment, there was a significant reduction in total CFUs per plate (mean, 384 CFUs vs 19 CFUs; $P < .001$), in the number of samples that tested positive for MRSA (81 [20.3%] of 400 plates vs 2 [0.5%] of 400 plates; $P < .001$), and in the MRSA counts per MRSA-positive plate (mean, 37 CFUs vs 2 CFUs; $P < .001$) (Table 2). The same relationship was revealed for VRE-contaminated patient rooms (data not shown).

DISCUSSION

UV irradiation has been used for the control of pathogenic microorganisms in a variety of applications, such as control of legionellosis, as well as disinfection of air, surfaces, and instruments.[10-12] At certain wavelengths, UV light will break the molecular bonds in DNA, thereby destroying the organism. UV-C has a characteristic wavelength of 200–270 nm, which lies in the germicidally active portion of the electromagnetic spectrum of 200–320 nm. The efficacy of UV irradiation is a function of many different location and operational factors, such as intensity, exposure time, lamp placement, and air movement patterns.[10-12] These studies showed that this technology is an acceptable and environmentally friendly method to disinfect surfaces in healthcare facilities.

The system that we evaluated is unique in that it uses measured UV-C intensities reflected from the walls, ceilings,

floors, or other items in the room and calculates the operation time required to deliver the programmed lethal dose for microorganisms.[8] The ability of the device to deliver lethal doses of UV-C to epidemiologically important microorganisms on nonreflective surfaces was evaluated, and we found that the quantities of these organisms were significantly reduced, reproducibly by 3–4 $\log_{10}$, under high contamination levels that exceed the levels normally found in healthcare facilities. In fact, studies have shown that, although the frequency of contamination by these pathogens (eg, *C. difficile*) is high (10% to more than 50%), the microbial load is generally low (less than 10 to 100 CFUs per plate or sample).[13]

In our experiments, we did not preclean the surfaces in patient rooms before treatment with UV-C. However, because the presence of dirt and debris can decrease the effectiveness of UV-C disinfection, rooms should be cleaned before UV-C treatment. Use of a precleaning step, such as wiping all surfaces and objects with an Environmental Protection Agency–registered disinfectant, followed by UV-C exposure should effectively decontaminate the surfaces and objects in the room. During the second phase of the study, we studied situations in which the bioburden levels are those naturally found on surfaces. In these situations, UV-C is capable of completely inactivating the entire population of vegetative bacteria (eg, MRSA or VRE) within approximately 15 minutes.

All disinfection and sterilization technologies have both advantages and disadvantages, and healthcare workers must consider these issues and decide which product or process provides the greatest value to them in their infection prevention efforts. The advantages of this system include the following: biocidal activity is reliable against a wide range of pathogens; surfaces and equipment can be decontaminated; decontamination for vegetative bacteria is rapid (approximately 15 minutes); the heating, ventilation, and air conditioning system does not need to be disabled and the room does not need to be sealed; the process is residual free and does not give rise to health and safety concerns; there are no consumable products, so the only costs are capital equipment and staff time; and UV energy is distributed well in the room with use of an automated monitoring system. The disadvantages include the following: we do not know whether use decreases the incidence of healthcare-associated infections; decontamination is performed only at terminal disinfection (ie, not daily cleaning); all patients and staff must vacate the room or area; capital equipment costs are substantial; it does not remove dust and stains, which are important to patients and visitors; and it has sensitive use parameters (eg, UV dose delivered).

In summary, UV technology offers an option for room decontamination in healthcare facilities. MRSA, VRE, MDR *A. baumannii,* and *C. difficile* spores comprise a growing reservoir of epidemiologically important pathogens that have an environmental mode of transmission. Because contamination of environmental surfaces is common even after surface disinfection and because contamination of healthcare worker hands can transfer these pathogens to patients, resulting in substantial numbers of infections, this technology (and other effective room decontamination technology) should be considered for use in selected patient rooms and care areas to augment current surface disinfection practices. Because of the high frequency of failure of manual cleaning and disinfection to contact all surfaces, room decontamination units, such as those using UV-C and hydrogen peroxide vapor, should be considered for use when the environmental mode of transmission is important.

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Address reprint requests to William A. Rutala, PhD, MPH, Division of Infectious Diseases, Bioinformatics, University of North Carolina at Chapel Hill, 130 Mason Farm Road, Chapel Hill, NC 27599-7030 (brutala@unch.unc.edu).

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Appendix C

Study on the

Effect of germicidal UV-C light (254 nm) on eggs and adult of house dustmites,

Dermatophagoides pteronyssinus and
Dermatophagoides farinae
(Astigmata: Pyroglyhidae)

Abstract

Objective

To examined the immediate and 24 hours post- irradiation germicidal effects of UV-C lamp on eggs and adults of house dust mites *Dermatophagoides pteronyssinus (D. pteronyssinus)* and *Dermatophagoides farinae (D. farinae)*.

Methods

This study investigated the immediate and 24 hours post irradiation mortalities of adult mites exposed to UV-C at different exposure times (5 mins, 10 mins, 15 mins, 20 mins, 30 mins and 60 mins) and distances (10 cm, 25 cm, 35 cm, 45 cm and 55 cm). Fresh eggs of the 2 dust mites were also irradiated at 10, 35 and 55 cm for 0.5, 1, 2, 3, and 5 minutes, and observed daily post- irradiation for up to 7 days.

Results

Highest immediate mortality of 100% occurred with direct irradiation at 10 cm distance from UV-C lamp and for 60 mins, for both species of mites. The post 24 hours mean mortality rates were (58.4±17.4)% for D. pteronyssinus and (27.7±9.7)% for *D. farinae* when irradiated for 1 hour at 55 cm distance under UV-C lamp. When mites were irradiated in the presence of culture media, the highest mortality rates were lower compared to the direct irradiation; at 10 cm distance and 60 mins exposure, the mean mortality was (74.0±6.8)% for *D. pteronyssinus* and (70.3±6.7)% for *D. farinae.* Egg hatchability for both species of mites was also notably reduced by greater than 50% following irradiation.

Conclusions

Ultraviolet C irradiation is lethal to an array of organisms by damaging their nucleic acids (DNA and RNA). This study demonstrates the increasing mite mortalities with increasing exposure times and decreasing distances.

Keywords: Physical control, UV-irradiation, *Dermatophagoides farina*, *Dermatophagoides pteronyssinus*, Mortality

Introduction

House dust mites (HDM) are found in most homes. They are microscopic, eight-legged creatures closely associated with us, but they are not parasitic and do not bite. The concern about HDM is that some species produce allergens affecting humans. The HDM allergens cause allergic symptoms such as asthma and atopic dermatitis in atopic humans. A number of the allergen producing HDM belongs to the family Pyroglyphidae. Pyroglyphid mites usually account for >90% of the mite population in houses. Dermatophagoides farinae and Dermatophagoides pteronyssinus are considered among the most important pyroglyphid mites because of their cosmopolitan occurrence and abundance in homes.

There are various approaches for the control of house dust mite and their allergen such as by reducing indoor relative humidity to below 50%, coupled with regular cleaning and use of encasement on mattress and pillows. Several chemicals have been examined in laboratories but their effectiveness in the home is controversial or even if effective, they have not been commercialized for home use because have potential problems of toxicity to non-targets such as humans and pets, produce unpleasant odor, damage household items, and unable to penetrate deeply into carpet and upholstery. Physical strategies like irradiation has become an established technique for controlling aeroallergens because of residue free advantages over chemicals. UV irradiation is widely used as a germicide and as an attractant for insects, in embryological physiological studies and for the surface disinfection of insect eggs. Wharton reported that UV irradiation (254 nm) killed nymphs of the American cockroach, Periplaneta americana. A number of other investigators also have considered the possibility of using UV rays to control, or at least to suppress development of various aeroallergens and insects. Ultraviolet light is known to damage or kill living organisms because it will destroy the DNA by forming covalent bonds between certain adjacent bases in the DNA, thereby preventing further replication and growth.

Ultraviolet C (UV-C) is a short wavelength (100-280 nm) radiation and is primarily used for the disinfection of air, surfaces and liquids from microbial contaminants. To date the UV-C is the wavelength in germicidal applications and is also recommended by the Centre for Disease Control and Prevention. Ultraviolet light air purification has been used for years by the medical field to sanitize rooms and equipment in order to prevent the spread of illness and disease. High intensity UV light modifies proteins as well, so it is possible that UV light might render an allergen non-allergenic. The efficacy of UV-C had been previously demonstrated against some stored product beetle and mite pests with sensitivity varying with species and doses. It is, however, difficult to make direct comparisons between studies as the level of UV dose achieved is not always stated and UV intensities vary with light sources. Long lists of bacteria, viruses and moulds also are often quoted to assert the killing power of UV-C. The implication that goes with those long lists is often made that UV-C will be just as effective on HDM.

The aim of this study is to investigate the mortalities induced by UV-C irradiation on eggs and adults of 2 species of HDM, *Dermatophagoides pteronyssinus* (*D. pteronyssinus*) and *Dermatophagoides farinae* (*D. farinae*).

Materials and methods

2.1. Sources of mites

Adult males and females *D. pteronyssinus* and *D. farinae*, and their eggs, were obtained from colonies established since 1960 in the Acarology Unit, Institute for Medical Research (IMR), Malaysia. The colonies are reared in small glass bottles and sterile ground rat chow mixed with fish flake is used as culture medium. All bottles are kept in desiccators at (75±3) % relative humidity (RH) and at an average room temperature of (25±2) °C.

2.2. UV-C radiation source

The radiation source was a 30 watts UV germicidal lamp (G30T8, Sankyo Denki, Japan) measuring 88 cm x 2.5 cm, and emitting radiation at a wavelength of 254 nm. The lamp was fixed to the ceiling of a Laminar Flow cabinet (120 cm x 63 cm x 50 cm) that served as a test chamber; another similar cabinet without the lamp was used for controls. Bioassays were conducted at a room temperature of (25±2) °C.

2.3. Bioassay with adult mites for direct exposure

Sets of 30, 15 - 25 days old adult mites of mixed male and female were placed in Petri dishes of 14 cm diameter and 1.5 cm high. The dishes and mites were next placed inside the UV-C chamber and irradiated for different times (5, 10, 15, 20, 30 and 60 mins) and at different distances (10, 25, 35, 45 and 55 cm) from the UV lamp. Controls were similarly treated in the control chamber. Three replicates were tested and the procedure was repeated 3 times for each irradiation time and distance. The exposed mites were examined immediately after irradiation under 400x magnifications and the number of dead mites was recorded. Mites that do not move when gently prodded were considered dead. Irradiation mites were maintained at (75 ± 3) % RH and (25 ± 2) °C and mortalities were determined again after 24 hours.

2.4. Bioassay with adult mites in presence of culture medium

Thirty 15 - 25 days old adult mites of mixed male and female were placed in clean glass Petri dishes, 14.0 cm diameter and 1.5 cm high along with 0.25 g of sterile culture medium. The Petri dishes were then placed inside the UV-C chamber and irradiated at

different exposure times and distances as above for direct exposure. Controls were similarly prepared but placed in the control chamber. There were 3 replicates for each treatment and the test was repeated 3 times. The number of dead mites after irradiation was examined under 400x magnification and the immediately mortalities were recorded. Irradiated mites were maintained at (75±3)% RH and (25±2) °C and mortalities were determined again after 24 hours.

2.5. Bioassay with eggs

Ten freshly oviposited eggs were collected using fine applicator sticks and placed in glass Petri dishes, 9.0 cm diameter and 1.2 cm high. The Petri dishes with eggs were placed inside the test chamber and irradiated for 0.5, 1, 2, 3 and 5 mins at distances of 10, 35, and 55 cm, from the UV lamp. Control eggs were similarly irradiated in the control chamber. After treatment, eggs were placed individually in clear glass vials measuring 3.5 cm high and 2.0 cm diameter that were secured with snap caps. The eggs were maintained at (75±3) % RH and (25±2) °C; hatchability was monitored daily for a week. All treatments were replicated 3 times, and the experiment repeated once.

2.6. Data and statistical analysis

Mean mortalities were compared and analyzed by independent sample *t*-test and one-way ANOVA at 95% confidence level using SPSS ver 11.0.

Results

3.1. Immediate mortalities of D. pteronyssinus and D. farinae for direct irradiation

Mortality rates for direct irradiation of *D. pteronyssinus* and *D. farinae* at difference exposure times and distances are shown in Table 1. No control mites died. Generally, mortality rates for both species, increased with increasing exposure times and decreasing distances. At 10 cm distance from lamp and 60 minutes exposure, 100% mortality resulted in both species of mites. For similar exposure times at 55 cm distance from lamp, there was significant difference among species ($P<0.05$); the mean mortality rates were (32.5±8.9) % for *D. pteronyssinus* and (11.0 ± 9.8) % for *D. farinae*. Increasing the exposure period at each distance significantly increased mortalities ($P<0.01$) of both species. There was significant increase in *D. farinae* mortalities at each exposure period with decreasing distances ($P<0.01$); similar with *D. pteronyssinus* ($P<0.03$) except at 15 minutes exposure where the differences were not significant ($P=0.16$).

Table 1
Immediate mortalities and 24 hours post mortalities (%, mean ± SD) of D. pteronyssinus and D. farinae directly irradiated at difference distances and exposure times.

Species	Distance (cm)	Immediate mortalities						24 hours post mortalities					
		5 min	10 min	15 min	20 min	30 min	60 min	5 min	10 min	15 min	20 min	30 min	60 min
DP	55	0.0±0.0	2.2±2.8	4.0±4.0	5.5±5.5	8.8±5.5	32.5±8.9	1.8±2.3	7.0±3.8	9.2±6.8	12.9±12.2	13.6±8.5	58.4±17.4
	45	0.3±1.1	4.7±4.4	5.5±4.0	11.0±7.0	38.1±9.7	38.4±9.8	2.2±2.8	11.8±4.7	10.7±2.7	15.8±9.8	48.1±13.5	68.1±12.3
	35	2.2±1.6	6.2±4.2	7.7±5.9	12.9±4.2	55.8±9.6	74.7±9.7	4.7±2.3	9.2±6.8	12.2±8.9	18.1±5.0	69.9±7.9	98.8±2.3
	25	4.4±2.8	8.4±4.1	8.4±5.2	27.0±9.6	69.2±9.5	97.0±4.2	7.3±5.2	11.8±5.2	15.5±10.4	41.8±12.4	80.3±12.4	100.0±0.0
	10	4.4±3.3	8.8 ±7.6	11.0±9.7	35.9±9.3	88.8±9.6	100±0.0	8.8±5.2	15.5±6.6	16.6±11.7	54.0±17.2	96.6±4.4	100.0±0.0
DF	55	0.0±0.0	1.1±2.3	1.8±2.3	1.1±1.6	5.9±4.6	11.0±9.8	2.2±2.3	6.2±3.5	8.4±5.0	8.5±4.4	8.6±6.4	27.2±9.7
	45	0.3±1.1	1.4±3.3	2.2±3.3	2.9±3.5	6.2±3.5	16.6±9.9	2.5±3.2	6.9±5.1	9.6±2.6	13.6±6.9	9.9±6.6	26.2±12.3
	35	0.7±1.4	1.8±2.3	4.0±2.2	19.2±8.2	44.0±8.6	57.3±10.5	6.2±3.1	7.0±5.6	10.3±3.8	28.8±11.0	52.9±8.4	86.9±9.3
	25	3.3±1.6	4.7±3.3	6.6±2.3	19.6±7.8	49.6±10.9	90.3±10.1	8.4±2.9	10.3±5.3	14.0±4.9	29.2±15.0	79.2±14.1	99.6±1.1
	10	4.4±3.3	5.5±3.3	7.7±1.7	39.2±9.8	72.9±10.9	100.0±0.0	8.4±3.7	12.9±4.8	14.0±3.6	47.3±11.4	85.1±14.7	100.0±0.0

DP-*D. pteronyssinus*, DF-*D. farinae*.

3.2. 24 hours post irradiation mortalities of D. pteronyssinus and D. farinae for direct exposure

D. pteronyssinus and *D. farinae* mortalities at all distances were significantly different between exposure times ($P<0.05$) (Table 2); 5 minutes exposure caused the lowest mortalities. At each exposure time, there were significant differences in *D. pteronyssinus* mortalities between various distance ($P<0.01$), however the difference were not significant for 15 minutes exposure times ($P=0.34$). For *D. farinae* mortalities, there were significant difference for all exposure time ($P<0.03$). At 60 minutes exposure time and 55 cm distance, the mean mortality rates by species were significantly different from each other ($P=0.001$).

3.3. Immediate mortalities of D. pteronyssinus and D. farinae in presence of culture media

Overall the mean mortality rates after exposure to UV-C in the presence of culture media for both mites were lower compared to the direct exposure. It is shown in Table 3 that mortalities increased with decreasing distance from the UV-C lamp. There was no death in the controls. At the highest exposure time of 60 min and 10 cm distance, there was no significant difference among species ($P=0.97$); the mean mortality rate were (74.0±6.8)% for *D. pteronyssinus* and (70.3±6.7)% for *D. farinae*. At the same exposure time but 55 cm distance, the mortalities between *D. pteronyssinus* and *D. farinae* were not significantly different ($P< 0.05$). Increasing the time exposed to UV-C at each distance significantly increased the mortalities of both species of mites ($P<0.01$). Decreasing distance from the UV lamp at each exposure times significantly increased the mortalities of *D. pteronyssinus* ($P<0.01$) but for *D. farinae* mortality significantly increased at each exposure ($P<0.05$) except at 5 minutes ($P=0.07$).

Table 3
Immediate mortality rates (mean ± SD) of *D. pteronyssinus* and *D. farinae* in the presence of culture media at different exposure period and distances from UV-C lamp.

Species	Distance (cm)	Exposure time (minutes)					
		5	10	15	20	30	60
D. pteronyssinus	55	0.0±0.0	0.3±1.1	1.1±1.6	1.8±2.3	2.9±1.9	12.1±6.4
	45	0.0±0.0	0.7±1.4	1.1±1.6	5.5±4.6	5.5±2.3	26.6±8.9
	35	1.1±1.6	2.9±2.5	4.7±3.3	10.7±4.0	22.5±7.2	37.0±8.8
	25	2.5±2.7	3.6±3.5	7.0±4.5	17.7±4.4	40.3±6.3	69.9±10.0
	10	2.5±2.7	4.7±3.3	7.7±2.3	31.0±8.1	64.0±5.4	74.0±6.8
D. farinae	55	0.0±0.0	0.0±0.0	1.1±1.6	0.7±1.4	4.0±3.2	6.9±3.8
	45	0.0±0.0	0.3±1.1	1.1±1.6	2.5±2.2	4.7±2.9	19.5±7.1
	35	0.7±1.4	2.2±2.8	2.9±3.0	9.2±4.6	22.9±8.2	30.7±3.2
	25	1.8±2.9	1.4±1.7	4.4±3.7	17.3±4.3	36.6±6.2	69.9±10.0
	10	1.8±2.3	4.0±4.0	6.2±3.5	34.0±10.8	62.5±4.9	70.3±6.7

3.4. 24 hours post irradiation mortalities of D. pteronyssinus and D. farinae in presence of culture media

It is shown in Table 4 that *D. pteronyssinus* and *D. farinae* mortalities were significantly difference at all exposure times for various distance ($P<0.01$). At each distance, there was significant differences in *D. pteronyssinus* and *D. farinae* mortalities between various exposure times ($P<0.05$). However, at the 10 cm distance with the longest exposure time the mean mortality rates by species were not significantly different from each other ($P=0.40$).

Table 4
Hatchability (%) of controls and eggs exposed to UV-C for 5 minutes.

Species	Distance (cm)	Eggs	Days post irradiation						
			1	2	3	4	5	6	7
D. pteronyssinus	55	Control	0	0	24	60	76	84	88
		Irradiated	0	0	0	0	0	0	0
	35	Control	0	0	0	30	40	54	82
		Irradiated	0	0	0	0	0	0	0
	10	Control	0	4	14	32	52	68	74
		Irradiated	0	0	0	0	0	0	0
D. farinae	55	Control	0	0	28	56	84	96	96
		Irradiated	0	0	0	0	0	0	0
	35	Control	0	4	4	24	42	52	58
		Irradiated	0	0	0	0	0	0	0
	10	Control	0	10	32	46	52	52	60
		Irradiated	0	0	0	0	0	0	0

3.5. Egg hatchability

No eggs hatched when exposed to UV-C radiation at any of the exposure times and distances; in comparison, >70% of the control eggs hatched. Most (88%) of the treated eggs were dry on day 3 post irradiation. Microscopic examination immediately after irradiation showed no difference with controls and irradiated eggs that fail to hatch; however day 3 post irradiation, treated eggs were wrinkled and dry (Figure 1). This is probably due to leakage of the inner contents when the chorions of treated egg wrinkled. For *D. farinae*, 122 out of 150 (71.3%) control eggs were hatched while 81.3% of *D. pteronyssinus* control eggs were hatched into viable larvae (Table 4).

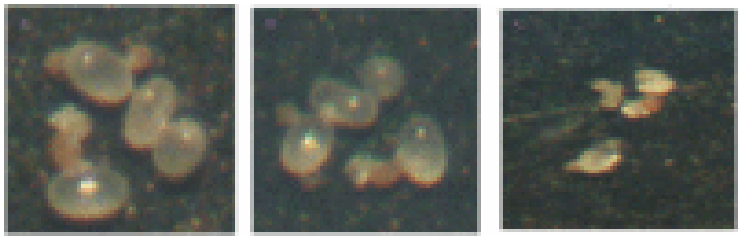

Figure 1.
Microscopic examination of UV-C irradiated eggs.

Discussion

The findings demonstrated UV-C radiation affected the egg stages more than the adult mites. It is possible for ultra-violet radiation to stop the development of house dust mites at early stage of its life cycle because none of the treated eggs hatched. This effect probably was due to the thinness of the chorion and the delicateness of the dust mite eggs in general. Needham *et al* came out with similar results and concluded that UV-C has potential to break the life cycle of house dust mites by killing the embryonic stage thus stopping the production of allergens. The nature of the UV-C effect on early developmental stages of mites is attributed to transmission of UV energy into the tissues. Provided it reaches the cells, UV-C radiation is able to impair cellular functions directly by damaging DNA, or indirectly by inducing increased formation of reactive free radicals leading to oxidative stress.

In the present study, the mortality of irradiated mites was directly proportional to the exposure times but indirectly with distances. Similar increase in adult mortality was reported by Faruki *et al* working with UV-irradiated of *A. diaperinus*. This finding agreed also with the results of Faruki *et al* working with the Almond Moth, Cadra cautella using UV rays mentioned that larval mortality was positively correlated with radiation exposure periods. Begum *et al* also conducting a similar study with darkling

beetle and reported that 100% reduction in the population which was exposed to UV-irradiation at certain times. Germicidal effect of UV-C also would be lethal to mites because of their small size; i.e., their body surface area per weight is large thus accelerate rate of UV absorption and dispersion of damage.

Our results also show there was significant difference in immediate and 24 hours post irradiation mortalities between *D. pteronyssinus* and *D. farinae* when directly irradiated at longest distance and times. This would suggest that UV-C treatment may have affected the mites quickly and thus killed them immediately. The recovery of mites from irradiation effect was very slow in most cases, which agrees well with other studies. In case of post 24 hours mortality for the same treatment, the mean mortality rates of *D. pteronyssinus* were significantly higher than *D. farinae*; it could be due to *D. farinae* mites more resistance to UV radiation or *D. pteronyssinus* has been in a poorer condition to begin with.

Although UV-C radiation kill dust mites, its application to control of such house dust mites population in their natural habitat such as mattresses or carpet, is not yet practical because it requires a prolonged exposure and has inherent operational drawbacks which are likely to influence its accuracy. One possible application is combating pest infestations associated with the structure of a building and may serve as a potential new hygiene measure. The limited penetration however precludes its use as a treatment on bulk commodities. It may also be able to offer potential as a surface hygiene in empty stores. The lack of irradiation effect on lower mortality when food was present in this finding demonstrates the limited penetration of UV-C through substrates. Adult mites and eggs concealed in carpeting and dense fabrics may escape exposure to the UV-C light radiation altogether. House dust mites are found most of the time inside mattresses or carpet since the microclimate and dampness are often highly favorable to mites. In order for UV-C treatment to be fully effective, the mites must be directly exposed to the UV-C for the required duration; a shorter distance between the mites and the UV-C source is advantageous. Anything that can shield the mites from exposure, e.g., food particles, dust, debris will affect efficacy. Since mortality rates increase with increasing exposure period, irradiation for more than 1 hour may result in higher mortality rates. When radiation kills or suppress, dust mite colony will be minimal and allergen levels may kept below threshold. However, there is need a balance the effect on the mites with the effect on the store products or house materials since prolonged exposure to UV radiation may reduce the quality of the stored products.

The reduced egg hatching and adult mortality of HDM caused by UV-irradiation is promising from control point of view. It may be concluded that irradiation is a clean method to eliminate mite population and consequently allergen reduction. Practical applications of UV-C within the house environment may, therefore, lie in the treatment of structural and equipment surfaces such as conveyor systems. However, cleaning and weekly vacuuming of carpets and sofas in homes is an important consideration as the presence of particles may affect UV-C efficacy. Repeated UV-C irradiations are probably required because the shorter wavelength rays of UV-C can penetrate only surface of carpets and mattresses -a single UV-C exposure would not eliminate dust

mites and its allergen located in deeper layers of mattresses. The cost and safety implications of UV-C irradiation should also be considered and more comprehensive research is needed.

Authors

Ernieenor Faraliana Che Lah, Raja Noor Azreen Raja Musa, and Ho Tze Ming

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Footnotes

Conflict of interest statement: We declare that we have no conflict of interest.

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