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Bactericidal Activity of a Broad-Spectrum Illumination Source

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Several hours of exposure to Vita-Lite lamps, which have a unique spectral distribution, give significant killing of cells of *Staphylococcus aureus*.

The bactericidal effects of ultraviolet (UV) light are well known, and it is generally considered that a wavelength of 265 nm is the optimum. On the other hand, Kaplan with long-wave UV (366 nm) observed no killing of *Serratia marcescens* at doses up to 150,000 ergs/mm² (2). However, other authors have observed some killing effects from visible light without an appreciable content of short-wave UV. Of exemplary interest is the early report of Buchbinder et al. (1), who observed that streptococci of various strains on the surface of petri plates were killed to a significant extent by natural daylight as well as direct sunlight, both direct and filtered through ordinary window glass.

The availability of an artificial illumination source with a spectral distribution more closely matching that of natural sunlight than do usual fluorescent lights, particularly in the region below 500 nm, has made it of interest to examine the bactericidal activity of such illumination in a situation where this effect would be ancillary but desirable for health reasons, e.g., in a nursing home (4).

Light sources. Vita-Lite lamps (Duro-Test Corp., North Bergen, N.J.) are fluorescent lamps of conventional geometry and loading, designed to duplicate sun and sky radiation at a color temperature of 5,500 K (CIE D-5500 degrees K). About 5% of the total radiant power lies at wavelengths between 290 and 380 nm. The lamps were mounted in UV-reflecting ceiling fixtures in a large room in such a way as to produce even illumination throughout the room. Control illumination (in another room) was from standard cool-white fluorescent tubes mounted in standard ceiling fixtures. Intensities of illumination at the points of exposure of bacterial plates are given in Table 1.

Culture methods. Bacteria chosen for testing were *Staphylococcus aureus* (ATCC 6538) and *Serratia marcescens* (ATCC 13880). Both were grown in nutrient broth. The day before an illumination experiment, prepoured nutrient agar plates were inoculated by spreading 24- or 72-hr old cultures on the surface. The plates were refrigerated in the dark overnight and on the following morning taken to the rooms for exposure. Plates were uncovered and exposed to illumination at two distances, specified in Table 1. At time intervals up to 8 hr, exposed plates were removed from under the lights and covered to prevent further exposure. Colony counts were made after 24 to 48 hr of incubation at 37 C for *S. aureus* and at room temperature for *S. marcescens*.

TABLE 1. *Conditions of exposure of bacteria*

Light intensity	Vita-Lite	Cool-white fluorescent (control)
High	2 ft 10 inches from lights	10 inches from lights
	445 ft-c[a]	380 to 445 ft-c
Low	7 ft from lights (30 inches from floor)	7 ft 6 inches from lights (30 inches from floor)
	345 ft-c	26 to 30 ft-c

[a] Foot-candle values cosine corrected.

The survival data, expressed as percentage kill, are given for three experiments with *S. aureus* in Table 2. After 8 hr of exposure to Vita-Lite at either the high or low levels, there was an equivalent degree of killing, approximately 90%. Two hours of exposure produced very minimal kills, and 4 hr gave intermediate values showing a good dose relationship. As expected, exposure to cool white lights in standard fixtures produced little cell kill with the exception of the 4- and 8-hr samples in experiment 2. The absence of a dose-related effect and the lack of confirmation of this observa-

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TABLE 2. *Cumulative survival data (% kill) for S. aureus in experiments 1 to 3*

Light intensity	Exposure time (hr)	Expt 1		Expt 2		Expt 3 (24 hr)		Expt 3 (72 hr)		Pooled data (mean and SD)
		V[a]	CW[b]	V	CW	V	CW	V	CW	V
High	1	0	0							
	2	8	0	0	0	0	8	3	18	3 ± 4
	4	29	1	63	59	42	0	58	16	48 ± 16
	8			99	72	92	0	86	9	92 ± 7
Low	1	0	0							
	2	2	0	9	6	0	2	2	12	3 ± 4
	4	19	0	97	5	6	0	30	15	38 ± 41 (18 ± 12)[c]
	8			98	5	87	5	81	6	89 ± 9

[a] Vita-Lite.

[b] Cool-white fluorescent.

[c] Calculated from three values, 19, 6, and 30% kill. Plate counts of unilluminated controls: experiment 1, 1,230 ± 162; experiment 2, 456 ± 65; experiment 3, 24-hr culture, 423 ± 42; 72-hr culture, 265 ± 27.

tion suggested that it was due to some extraneous factor other than illumination.

S. marcescens, on the other hand, showed no measurable kill in either of two experiments with both light sources. Plates for the first experiment were incubated in the light, whereas those for the second were incubated in the dark. Since the results for the two sets agree, photoreactivation does not seem to have occurred during the incubation of the first experiment. Two alternative explanations for this lack of effect must be considered. The spectral distribution of the Vita-Lite lamp is such as to provide no radiation of wavelengths less than 290 nm which are known to be more bactericidal. Alternatively, it may be that photoreactivation or "photoprotection" occurred because of the simultaneous presence of longer wavelength radiation. Either of these mechanisms may be related to the presence of pigmentation in the cell, since ours is a pigment-producing strain. As indicated above, Kaplan noted that long-wave UV was not active against *S. marcescens*. It has been calculated that, under our conditions of exposure, the intensity of 320- to 380-nm radiation at 500 ft-c would be 103 $\mu w/cm^2$, giving a dosage in 8 hr of 2.95 w-secs/cm^2, or almost twice the 150,000 ergs/mm^2 reported by Kaplan to be ineffective. Recent work by Winkler and Heil (3) shows light of this wavelength (366 nm) to be highly active in photoreactivation in *S. marcescens*.

In conclusion, it may be stated that Vita-Lite lamps used at intensities recommended for illumination produced significant killing of *S. aureus* over protracted periods of exposure. High levels of such artificial daylight, including the small amount of UV normally present, could thus be of value in controlling air contamination with this and presumably other organisms where danger to personnel precludes the use of standard bactericidal lamps. The lack of success with *S. marcescens* may be a reflection of some unique properties of that bacterium and its photoreactivity.

LITERATURE CITED

1. Buchbinder, L., M. Solowey, and E. B. Phelps. 1941. Studies on microorganisms in simulated room environments. III. The survival rates of streptococci in the presence of natural, daylight and sunlight, and artificial illumination. J. Bacteriol. 42:353–366.
2. Kaplan, R. W. 1956. Dose-effect curves of s-mutation and killing in *Serratia marcescens*. Arch. Mikrobiol. 24:60–79.
3. Winkler, U., and K. Heil. 1969. A non-photoreactivable mutant of *Serratia marcescens*. Photochem. Photobiol. 9:99–102.
4. Wurtman, R. J., and J. Weisel. 1969. Environmental lighting and neuroendocrine function: relationship between spectrum of light source and gonadal growth. Endocrinology 85:1218.