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Bactericidal Effectiveness of Modulated UV Light

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Studies were designed to evaluate the effectiveness of pulsed modulated UV light waveforms for killing bacteria. Exposure of five strains of bacteria to the modulated information encoded in the light decreased the colony population from a confluent lawn to <20 colonies. However, ~2,000 colonies survived treatment with the same intensity and time of exposure to UV light lacking the modulated information.

Previous studies of the bactericidal efficacy of UV lamps have focused on the spectral characteristics of the bulb, wattage, intensity, and time of exposure (2). Most existing producers of germicidal lamps use high-power continuous-wave UV lamps which operate at the power line frequency of 50 or 60 Hz (2). These lamps are generally used to sterilize and disinfect hospital corridors, operating rooms, instruments, special "clean rooms," laminar flow hoods, and some food processing work areas.

The studies described below were designed to evaluate the effectiveness of computer-controlled modulated UV-C light in a series of in vitro experiments.

A pulsed germicidal lamp (PGL series C; RWI, Charleston, S.C.) in which the UV-C output is amplitude, phase, and frequency modulated was tested. These modulations were optimized by the manufacturer for bactericidal activity. The PGL system uses relatively low-intensity UV-C output (Fig. 1) and contains a state-of-the-art modulation and driver system based on microchip technology (R. J. Dratch, Proc. Inst. Electr. Electron. Eng., Electro '83, p. 28, 1983). This circuitry regulates the modulation with a precision greater than one part in 10^6.

Bacteria were exposed to the modulated output consisting of a cord of bactericidal frequencies or a "null" position, which does not incorporate the selected modulation. The null position served as a control which exposed the sample to the same intensity and duty cycle used in the bactericidal position. To minimize power level variability, all bacterial samples tested were exposed with the gain control (power level) set at 75% of its rated power (~6 W at average continuous power and 40 W at maximum peak power).

Four standard strains of bacteria associated with opportunistic infections were studied: *Escherichia coli* ATCC 25922, *Staphylococcus aureus* ATCC 25923, *Pseudomonas aeruginosa* ATCC 27853, and *Serratia marcescens* ATCC 8100. In addition, one strain (VAS9) of *Staphylococcus epidermidis* isolated at the Charleston Veterans Affairs Medical Center was studied.

The bacteria were grown in Trypticase soy broth for 24 h on a shaker at 30 oscillations per min. Log-phase cultures were diluted to approximately 10^9 bacteria per ml, and 0.1 ml was spread evenly on Trypticase soy agar (TSA) plates. The bacterial monolayers were exposed to either the modulated light containing the bactericidal information or the null position generated by the PGL at a distance of 31 cm for either 15 or 60 s. In most experiments, a portion of the plate was partially shielded from direct UV-C light exposure by the polystyrene lid of the petri dish; aluminum foil; 3, 6, 12, or 24 layers of gauze; white paper; brown paper; or one layer of white cotton or colored cotton-polyester blend cloth.

All experiments were performed in triplicate and scored without reference to the treatment code. All samples were incubated at 35°C for 24 h before scoring.

The bactericidal activity of the PGL was roughly equivalent for *S. epidermidis* VAS9, *P. aeruginosa*, *E. coli*, *S. aureus*, and *S. marcescens*. Exposure of the five bacterial cultures on TSA to UV-C light for 60 s at 31 cm resulted in a 6- to 7-log-unit decrease in numbers of viable bacteria (~4 J/M^2). The viable bacterial population decreased from a complete lawn to an average of 18 ± 14 colonies. After 15 s of exposure at 31 cm, 736 ± 318 colonies survived. Exposure of bacteria to the null position was far less effective in killing bacteria with >2,000 colonies surviving (Fig. 2b). This finding substantiates the hypothesis that encoding information enhances the bactericidal activity of UV-C light.

The bactericidal effectiveness was virtually eliminated when the UV-C light was partially occluded. The bactericidal effects were effectively blocked by one sheet of white (90% rag content) paper, brown Kraft paper, a glass microscope slide, aluminum foil, 12 or more plies of gauze, or closely woven cloth (Fig. 2).

UV-C light emission from the PGL was lethal to several common strains of bacteria following a brief exposure time of only 60 s at <31 cm. Substantial bactericidal action occurred after exposures of 15 s. The bactericidal effectiveness is limited to areas directly exposed to the UV-C light

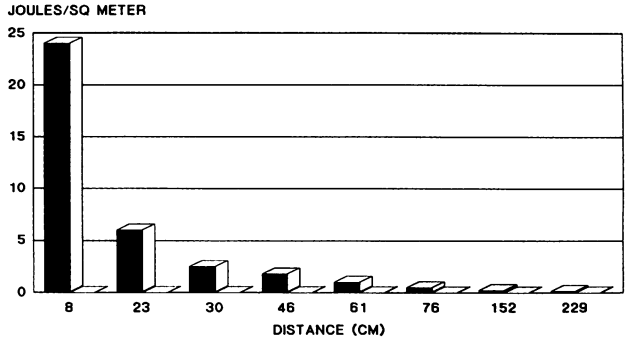

FIG. 1. Intensity of UV-C light versus distance with a 1-min exposure.

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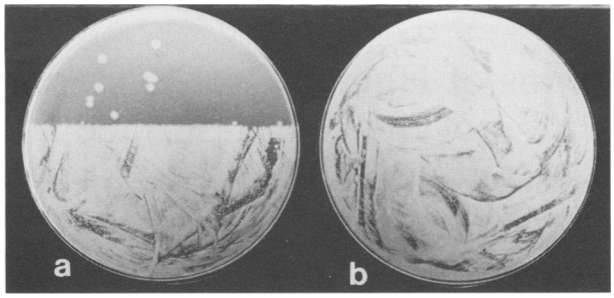

FIG. 2. (a) *E. coli* exposed to the PGL. The bottom half of the plate was covered with white cotton cloth. (b) *E. coli* colonies surviving exposure to the same intensity and time of exposure to UV light lacking the modulated information (null waveform position).

and can be reduced or eliminated by shielding with aluminum foil, paper, or closely woven cloth. Presumably, the bactericidal action is confined to the substrate surface because of the limited penetration of the short UV-C wavelength (1, 3). Exposure of these bacteria to an equivalent amount of UV-C light which did not have the bactericidal modulation (null position) was far less effective in killing bacteria ($>5 \times 10^3$ fewer colonies). The bactericidal effectiveness of the null position was roughly equivalent to published effectiveness values for conventional UV-C light. The high bactericidal effectiveness coupled with the lower energy output in the UV-A and UV-B range should enhance safety during use (1–3; Induced energies at 253.7 nm radiation, summary data sheets, American Ultraviolet Co., 1981).

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