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EFFICACY OF ULTRAVIOLET LIGHT IN PREVENTING *LEGIONELLA* COLONIZATION OF A HOSPITAL WATER DISTRIBUTION SYSTEM*

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Abstract—We performed a controlled evaluation of ultraviolet light irradiation of hot and cold water supplies in a hospital colonized with *Legionella* by inserting the u.v. units near the "point-of-use". Showers on one wing of a hospital were supplied with u.v.-irradiated water. Showers on another wing and 20 other outlets served as controls. Cultures prior to the installation of u.v. units showed all outlets to be heavily colonized with *L. pneumophila.* Despite disinfection of incoming water by u.v., *Legionella* in established niches of the plumbing system continued to survive. Superheat/flush and chlorination was then applied prior to u.v. activation. Although cultures became negative initially, recolonization occurred after 1 month. Scale accumulation on u.v. lamps had compromised the efficacy of u.v. irradiation. Filters were added to prevent scale accumulation on the u.v. lamps and the u.v.-supplied showers remained *Legionella*-free. U.V. plus prefiltration can prevent *Legionella* recolonization for at least 4 months after disinfection if the u.v. units are installed near the "point-of-use". Disinfection must be directed not only at incoming water, but also at established niches within the existing plumbing system. The advantages of u.v. include easy installation, low expense, and no adverse effects on water or plumbing.

Key words—building systems, hospital, hot water, filtration, treatment

INTRODUCTION

Potable water distribution systems are the source for *Legionella* infection (Best *et al.*, 1983; Farr *et al.*, 1988, Fisher-Hoch *et al.*, 1981). As a result, hospitals have instituted various disinfection modalities to prevent Legionnaires' disease by eradicating *Legionella* from their water systems.

Hyperchlorination and thermal eradication ("superheat and flush") are the two most widely used methodologies, despite major disadvantages for each. Ultraviolet light (u.v.) irradiation is a theoretically attractive alternative for disinfecting potable water systems. U.V. irradiation kills bacterial cells by producing thymine dimers in DNA which subsequently hampers DNA replication; maximal kill occurs at a lightwave length of 254 nm. *In vitro* laboratory (Antopol *et al.*, 1979; Knudson *et al.*, 1985; Yamamoto *et al.*, 1987; Gilpin *et al.*, 1984; Martiny *et al.*, 1989) and *in vivo* model assessments (Muraca *et al.*, 1987) of u.v. disinfection have established that u.v. is bactericidal for *Legionella pneumophila*; however, only limited anecdotal and inconclusive observations on the efficacy of u.v. disinfection of *Legionella* in large-scale potable water supplies have been reported (Baker *et al.*, 1990, Farr *et al.*, 1988). Controlled evaluation of this disinfection method in a hospital water system has not been performed. In this study, we examined the efficacy of u.v. disinfection of *Legionella* near the "point-of-use" in a hospital building known to be persistently colonized with *L. pneumophila.* "Point-of-use" is a term used to describe u.v. installation on water pipes supplying a small area, such as a room, or several rooms. This is in contrast to u.v. installation on the incoming water supply for the entire building ("point-of-entry"). It is notable that previous attempts over a period of 5 years to eradicate *Legionella* from the water supply of this hospital using thermal eradication (superheat and flush) and shock chlorination had failed.

MATERIALS AND METHODS

Hospital

Evaluation was undertaken in a 541 bed VA medical center which provides services to veterans with psychiatric disorders. The area of the study site encompassed a total of 23,000 sq. ft with 75 rooms. From 1985 to 1988, approximately 800 cultures performed in a monthly surveillance protocol of 17 distal sites showed a mean *Legionella*

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positivity of 44% (range 21–85%) (omitting these negative cultures which occurred shortly after unsuccessful disinfection attempts with thermal eradication and shock chlorination).

Three showers in the west wing shower room of one building were selected as the "point-of-use" site for u.v. units (one for cold water line, one for hot water line). Three showers in the east wing shower room and 20 other water outlets on both wings that did not receive u.v. irradiation served as controls. Surveillance cultures of these sites in the 5 years prior to the installation of u.v. units showed that 30–80% sites were persistently colonized with *L. pneumophila* (mean 110 cfu/swab, range 1–300+ cfu/swab) (cfu = colony forming units of microorganism).

Ultraviolet unit

The u.v. unit has two lamps which radiate 254 nm short-wave u.v. light, providing a dosage of greater than 30,000 $\mu W \cdot s/cm^2$ (model MP-2-SL, Aquafine Co, Valencia, Calif.). The unit is furnished with a running hour meter and alarm lights. Two intensity meters were installed with the u.v. units. The unit can sustain a maximum flow rate of 20 gpm. The u.v. units were placed in the room next to the west shower room and were inserted on the hot and cold water lines supplying 3 showers; the pipe length from the u.v. units to the showers was 28 ft.

The maximum flow rate of the pipe supplying the u.v. controlled showers was 15 gpm (3 × 5 gpm) and the hot water temperature was 110°F. An intensity meter with alarm was used to measure u.v. intensity. The quartz sleeves of the u.v. units were cleaned manually or by pumping a cleaning solution through the chamber. The quartz sleeves were cleaned every 2 weeks or whenever u.v. intensity dropped below 80% of the original set point.

Culture methods

A standardized culture protocol was used to culture *Legionella* (Vickers *et al.*, 1987). Swabs were plated onto buffered charcoal yeast extract (BCYE) agar and an environmental selective/differential agar medium (DGVP) containing dyes, glycine, vancomycin, and polymyxin B (Vickers *et al.*, 1987). Each sample was plated onto 2 BCYE and 2 DGVP culture plates directly and after acid-treatment for a total of 4 plates per sample. Showers and sinks were cultured by swabbing the surfaces of shower heads and inner surfaces of water spigots. The sampling time interval was pre-start-up, 1 day, 1 week, and monthly after each experiment was initiated.

Specimen processing and isolate identification

The specimens were processed, as described elsewhere (Vickers *et al.*, 1987). This included the use of selective differential media and pretreatment of specimens with acid. The cultures were incubated for 5–7 days at 37°C in a humidified atmosphere, and colonies morphologically consistent with *Legionella* were subcultured on blood-agar and buffered charcoal yeast extract agar plates. Isolates were definitively identified by direct fluorescent antibody testing (Sci-Medx).

Assessment of u.v. efficacy—Stepwise approach

Experiment 1. U.V. alone without prior decontamination. This experiment was designed to assess the necessity for a stringent decontamination protocol prior to u.v. start-up. *Legionella* was already present within the system. The u.v. units were activated without disinfecting the piping and showers distal to the u.v. unit.

Experiment 2. U.V. following superheat/flush and shock chlorination. This experiment was designed to assess the efficacy of u.v. in a system free of *Legionella*. Prior to u.v. start-up, the pipes leading to the showers from the u.v. unit were decontaminated. Both the hot water and cold water lines leading to the showers from the u.v. units were filled with a sodium hypochlorite solution. Vinegar was added to the solution to keep the pH value less than 7.5. The chlorine solution was pumped into the lines through the u.v. cylinders and the chlorine concentration was monitored at the showers (> 200 ppm) using chlorine test strips (Micro-essential Laboratory, Brooklyn, N.Y.). The shower heads were soaked with chlorinated water. The chlorine solution remained in the lines overnight for approximately 18 h. The chlorine solutions were then flushed out until the chlorine residuals at the shower heads were (< 1 ppm) as measured using chlorine test strips. Then, the temperature of hot water supply was raised to 80°C by an instantaneous steam heater. The showers were flushed with superheated water (80°C) for 30 min.

Experiment 3. U.V. plus filtration following superheat/flush and shock chlorination. This experiment was designed to assess the efficacy of u.v. when filters were added to minimize accumulation of scale on the quartz sleeves of u.v. lamps. Two prefilters (5 μm) (Culligan Water Conditioning Co., Pittsburgh, Pa) were installed proximal to both the u.v. units (on both the hot and cold lines) (Fig. 1). The housing for the cold water filter was No. 15-1 which had a temperature limitation of 120°F. Dimensions of the unit were $12\frac{3}{4} \times 7\frac{1}{2}$ with 1″ FPT (female pipe thread) connection. Each cold water filter had one 5 micron cartridge. For the hot water the filter housing was stainless steel with 1″ FPT connections for two cartridges (9 3/4 × 2 1/4 cartridge). The housing size was approximately 23″ × 5″ diameter. Each unit has two WBRS-5 cartridges (5 μm). Prior to the u.v. start-up, the pipes leading to the showers from u.v. units were disinfected again applying the same disinfection procedure as for the u.v. following heat/flush and chlorination experiment.

Experiment 4. Filtration alone following superheat/flush and shock chlorination. This experiment was designed to assess whether the disinfecting efficacy of the u.v. plus filter could be attributed solely to the effects of the filter rather than the u.v. light. The u.v.-supplied showers with prefilters now served as the basis for comparison. The decontamination protocol was simultaneously administered to both the u.v. supplied showers and the control filtered showers. Two filters, identical to the prefilters installed with the u.v. units, were installed onto the hot and cold water lines supplying the control showers of the east wing. Prior to the u.v. start-up, the plumbing on both experimental and control wing leading to the showers were decontaminated by applying the same protocol as in Experiment No. 3.

Statistical analysis

The culture results from the u.v.-treated and control sites were compared by: (a) mean cfu/swab of all u.v.-treated sites vs all control sites (Student *t*-test), (b) percent of sites showing any *Legionella* positivity (positive or negative for *Legionella*) (χ^2, 2-tailed).

Graphs were constructed using the mean cfu/swab for three showers ±SEM. Data for an individual shower was the mean of the four evaluable culture plates. The vertical lines represent ±SEM. No vertical lines (SEM) are calculated for the u.v. plus filter in Figs 5 and 6, because all showers and all replicate plates yielded zero (0) growth.

RESULTS

Assessment of efficacy of u.v. units on Legionella colonization

Culture results shown below are results of the mean cfu/swab taken from three showers on the u.v.-supplied wing and three showers from the control wing with replicate plating for each shower. In the 6 months prior to initiation of experiments 1–4,

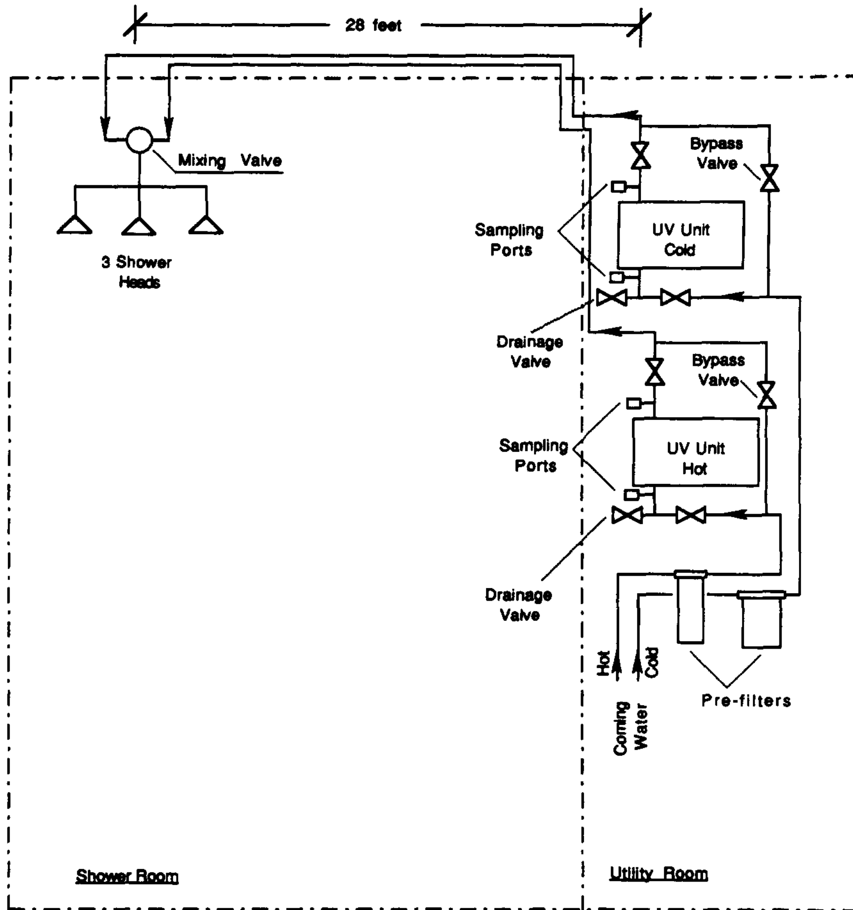

Fig. 1. Prefilters were installed before the u.v. units.

two of the three showers on the wing that would be u.v.-treated were consistently colonized with large numbers of *Legionella*, serogroups 1 and 6 (mean 187 cfu/swab, 95% confidence interval, 110–270).

Experiment 1. U.V. alone without prior decontamination. No change in *Legionella* concentration was seen in all the u.v.-supplied showers vs control showers (Fig. 2) i.e. u.v. proved ineffective. The mean cfu/swab in all the u.v. supplied showers was not significantly different from all the control showers (mean 189 cfu/swab vs 196 cfu/swab, $P = 0.91$, *t*-test). There was no change in non-legionella bacteria concentration in either u.v.-supplied and control showers.

Experiment 2. U.V. following superheat/flush and shock chlorination. One day after disinfection, cultures from u.v.-supplied showers were negative for *Legionella* and non-*Legionella* bacteria. One week after activation, the u.v.-supplied showers were *Legionella*-free, whereas the control showers remained positive. However, one month after the eradication, the u.v. supplied showers had recolonized with *Legionella* (Fig. 3). We found that the u.v. intensity readings frequently dropped below 80% and required cleaning up to 6 times during a 1 month period (Fig. 4). One month after the eradication, there was no longer a difference between the u.v. supplied showers and the control showers (mean cfu/swab 127 vs 71.33, $P = 0.64$, *t*-test). One

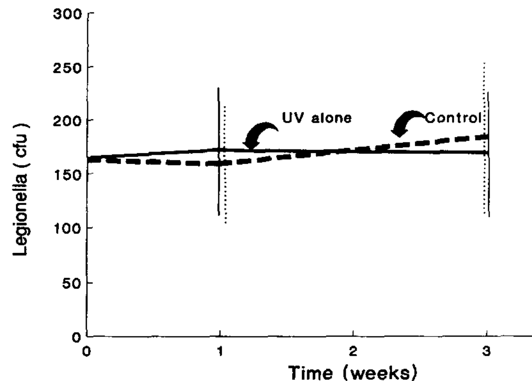

Fig. 2. Effect of u.v. disinfection without prior decontamination (Experiment 1). Each point is the mean cfu/swab of three showers; each shower represents four replicate plates. The vertical lines represent ±standard error of the mean.

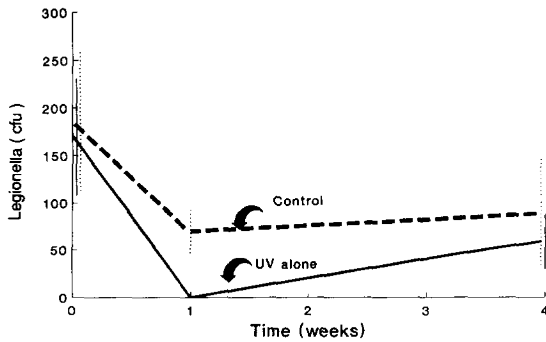

Fig. 3. Effect of u.v. disinfection following decontamination with superheat/flush and shock chlorination (Experiment 2).

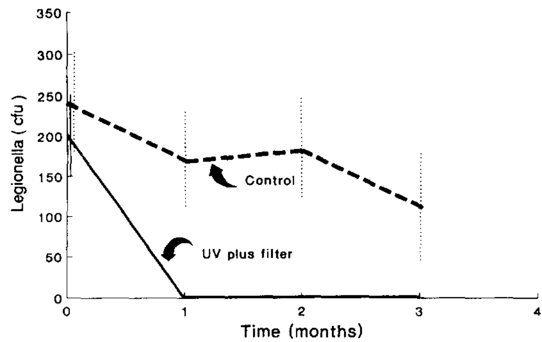

Fig. 5. Effect of u.v. plus filtration following superheat/flush and shock chlorination (Experiment 3). Standard errors of the mean were not calculated for u.v. because all showers and replicate plates yielded zero growth.

week after disinfection, the concentration of non-*Legionella* bacteria returned to 50% of baseline. One month after disinfection, non-*Legionella* bacteria had returned to baseline levels seen prior to disinfection. Levels of *Legionella* and non-*Legionella* bacteria remained unchanged at control sites.

Experiment 3. U.V. plus filtration following superheat/flush and shock chlorination. With the addition of prefilters to minimize accumulation of scale on the u.v. quartz sleeves of u.v. lamps, u.v. intensity was maintained at 100% throughout this experiment (Fig. 4). U.V.-supplied showers remained free of *Legionella* for 3 months (Fig. 5), whereas the control showers and sinks remained positive for *Legionella* at the same level as prior to u.v. start-up. In the fourth month, a power failure occurred for 4 h; low numbers of *Legionella* were subsequently cultured within three weeks of the power failure from the u.v.-supplied showers. The mean cfu/swab of the u.v.-supplied showers for the 6 month period following the decontamination protocol was lower than that of the control showers even when the period following the power failure of u.v units was included (mean cfu/swab 38.3 vs 107.9, $P = 0.08$, t-test). No non-*Legionella* bacteria were recovered 1 day and 1 week after disinfection. One month after disinfection, the concentration of non-*Legionella* bacteria at u.v.-supplied showers was 50% of the level before disinfection. Two months after disinfection non-*Legionella* bacteria concentrations had returned to baseline levels.

Experiment 4. Filtration alone following superheat/flush and shock chlorination. The control showers equipped with the filters alone became *Legionella* positive 1 month after the decontamination protocol. However, the u.v.-supplied showers plus prefilter continued to be *Legionella*-free for 4 months following the decontamination protocol (Fig. 6). We note that *Legionella* could be isolated from the filters and the inlet sampling port of the u.v. units, but not from the outlet sampling ports of the u.v. units. This showed that the effect of the filters was not mechanical removal of *Legionella*, but of minimizing scale on u.v. lamps such that u.v. was more efficacious. The mean cfu/swab for the 6 month period following the

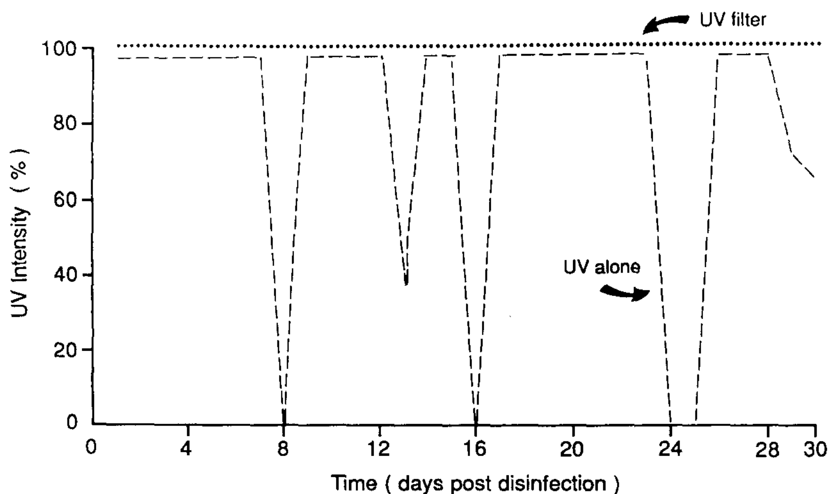

Fig. 4. The addition of prefilters maintained the intensity of the u.v. irradiation. Without prefilters u.v. intensity frequently dropped below 80%.

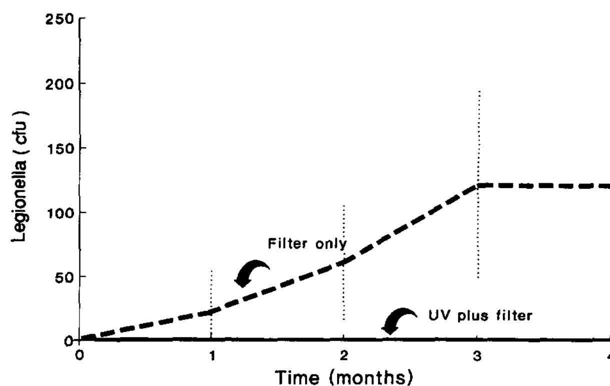

Fig. 6. Effect of filtration alone following superheat/flush and shock chlorination.

addition of filters to the control showers was significantly lower in the u.v. supplied showers (mean cfu/swab 107.3 vs 0.93, $P = 0.009$, t-test).

DISCUSSION

The efficacy of u.v. light disinfection for controlling *Legionella* in an actual hospital situation has not been well established in controlled evaluations. Farr *et al.* (1988) reported that continuous u.v. treatment of both cold and hot water combined with filtration was effective in preventing *Legicnella micdadei* (Pittsburgh pneumonia agent) recolonization of water fixtures of a hospital ward housing renal transplant recipients. However, before the u.v. units were activated, all pipes leading to the ward rooms were replaced and disinfected by hyperchlorination. Therefore the precise contribution of u.v. and the necessity of disinfection of the existing biofilm could not be evaluated.

Baker *et al.* (1990) demonstrated that u.v. (Aquafine Co., Valencia, Calif.) combined with metallic ionization (LiquiTech, Burr Ridge, Ill.) and chlorination maintained a hospital water system *Legionella* free for 31 weeks. Unfortunately, the three disinfection modalities were evaluated simultaneously without controls so the relative contribution of each modality was uncertain. Makin *et al.* (1993) found that u.v. was effective in maintaining one shower free of *Legionella* for 16 months. This shower was first autoclaved and hyperchlorinated prior to u.v. activation.

A 5-year chronicle of persistent *Legionella* colonization in a VA hospital in Pittsburgh showed that seasonal variation or abrupt decreases in the level of contamination was minimal. This was important in our evaluation in that any fluctuations of *Legionella* counts might be confused with the effects of disinfection. In this hospital, disinfection using superheat and flush and shock chlorination was followed by recolonization within two months.

We hypothesized that *Legionella* recolonization was due to bacterial regrowth in the biofilm lining the internal surfaces of piping. Legionella may persist within the scale and dead-end piping and could be shielded from the chlorine and heat disinfection. By installing the u.v. units near the "point of use" water outlets, the plumbing system area receiving irradiated water would be considerably smaller so that recontamination from dead end sections of pipe or from stagnant areas elsewhere would be minimized. Therefore, the insertion of u.v. units near the "point-of-use" might prevent *Legionella* recolonization. We assessed the efficacy of the u.v. units in a stepwise fashion with the four experiments described in the Methods (Figs 2, 3, 5 and 6).

Since u.v. light provides no residual protection, regrowth of *Legionella* in the biofilm layers of scale and accumulated debris allowed recolonization in pipes and outlets despite receiving u.v.-treated radiated water. Therefore, decontamination with superheat/flush and chlorination prior to u.v. activation was necessary to maximize u.v. efficacy (Fig. 2).

Nevertheless, *Legionella* recolonized the u.v. supplied showers one month following decontamination and u.v. activation (Fig. 3). We then learned that accumulation of scale on the u.v. lamps had decreased the intensity level of u.v. irradiation such that the units were no longer effective. When filters were installed to prevent scale accumulation (Fig. 1), the u.v.-supplied showers remained free of *Legionella* for four months, the duration of the experiment (Fig. 5).

Our final experiment demonstrated that the effect of the filters was to minimize the accumulation of scale on the u.v. quartz sleeves rather than any inherent disinfecting effect. This was confirmed when the control showers with the filters alone proved incapable of maintaining the showers free of *Legionella* (Fig. 6), whereas the u.v.-supplied showers with prefilters remained free of *Legionella* during the four month duration of this experiment.

In summary, u.v. disinfection proved effective for short-term control of *Legionella* colonization in a limited controlled area of a hospital. Not only did *Legionella* counts significantly decrease with u.v. irradiation, but other commensal water microflora

also decreased commensurately. The advantages of a u.v. system include relatively low cost, modular installation, and easy maintenance. It is a continuous physical disinfection measure without residual chemicals that may be carcinogenic for man or corrosive for the plumbing. Water quality, taste, and temperature are unaffected.

However, some steps must be taken for maximal efficacy. Since u.v. provides no residual protection, a stringent decontamination protocol must be initiated prior to u.v. start up. U.V. units must also be combined with prefiltration to maintain u.v. irradiation intensity. Proper maintenance and cleaning of u.v. lamps is necessary. U.V. might be better used as a supplementary disinfection method rather than a single primary method. Furthermore, the u.v. units should be located near the "point-of-use". Matulonis *et al.* (1993) have demonstrated the efficacy of u.v. in combination with intermittent chlorination in a bone marrow transplant unit. Further studies of u.v. disinfection over longer duration is appropriate but the principles elucidated above should maximize the utility of this method.

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