Ultraviolet Light-Resistant Viruses Revealed

By Kelly A. Reynolds, MSPH, Ph.D.

Waterborne adenoviruses cause significant illness worldwide and have high fatality rates in immunocompromised individuals. The increased use of ultraviolet (UV) light to treat drinking water has led to concern over adenovirus resistance to UV. New research, however, indicates that these viruses may not be as resistant as previously thought. Properly designed UV systems appear to easily control waterborne viruses, including adenovirus.

UV light disinfection

The process of disinfection is not designed to destroy all microorganisms but rather reduce their numbers to an acceptable level. Chlorine is the most commonly used disinfectant for water treatment in developed countries, due to its proven efficacy and low cost; however, the production of harmful disinfection byproducts in the environment are a constant concern. In response to this concern, UV light has been increasingly applied as an alternative drinking and wastewater disinfectant. In addition, UV is known to be effective against a wide range of microbial pathogens, including the chlorine-resistant *Cryptosporidium*.

On the electromagnetic spectrum, UV light falls between X-rays and visible light (wavelengths of 180 to 380 nm). UV will not improve the taste, odor or clarity of the water but it will inactivate protozoan, bacterial and viral pathogens. The most effective wavelength for inactivation of microbes is between 253 and 265 nm, where improper bonds form between nucleic acid bases, preventing replication of the organism and eventually death.[1]

UV lamps used for water treatment are generally either medium- or low-pressure mercury lamps. Some of the previously recognized disadvantages associated with UV light disinfection are: 1) hazardous mercury lamps; 2) high electrical power needs; 3) reduced efficacy in turbid waters and 4) the possibility of photo-reactivation of microbes, particularly human adenoviruses.

New improvements and uses of UV light have addressed many of these concerns. Mercury-free lamps have been recently developed that produce a higher UV efficiency, resulting in lower electrical costs.[2] The basis of this technology is the use of pulsed, surface-discharge lamps. Unlike medium- and low- pressure UV systems containing mercury, pulsed UV lamps contain xenon vapor and, with proper design, may deliver doses of 650 to 1,000 mJ/cm^2 during treatment of drinking water.[3] The question remains, however: could these newer pulsed UV light systems address the concern of UV-resistant adenoviruses in drinking water?

Adenoviruses are known to survive longer in the environment than other waterborne viruses, likely due to their hearty double-stranded DNA structure… Conventional UV disinfection inactivates viruses by damaging their RNA or DNA; however, the double-stranded DNA characteristic of adenoviruses enables the virus to be repaired once inside a host cell. Thus, adenoviruses have emerged as the most resistant waterborne virus to UV light…

More stringent US EPA treatment regulations

Following 1996 amendments to the *Safe Drinking Water Act*, US EPA promulgated the *Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)* requiring unfiltered drinking water supplies to be disinfected with a minimum of two disinfectants, including one designed to inactivate *Cryptosporidium*. More recent regulations from the agency were specifically focused on the need to treat drinking water to reduce exposures to human viruses. While there are no regulatory standards specifically for adenoviruses, the *LT2ESWTR* states that a UV dose of 186 mJ/cm^2 is required for a four-log (99.99 percent) reduction of viruses. This requirement varies from previous rules where a 40 mJ/cm^2 dose was thought to be efficient for virus inactivation.[4] Likewise, the *Groundwater Disinfection Rule* (promulgated in 2007) states that UV light disinfection must be accompanied with additional virus inactivation treatments.[3] These cautionary regulations were largely aimed at the UV-resistant adenoviruses. Researchers, however, have questioned the resistance of adenoviruses calling for more studies on the true effects of UV disinfection on the virus' infectivity in human hosts.

Adenovirus UV resistance

At least 52 different species of adenoviruses have been identified, with approximately one third associated with human disease. Depending on the strain, adenoviruses may be transmitted by ingestion or exposure to contaminated aerosols (i.e., the fecal-oral or respiratory route), causing a wide range of symptoms including: colds, sort throat, bronchitis, pneumonia, diarrhea, conjunctivitis (eye infection), fever, cystitis (bladder infection), rashes, neurologic disease or ear infection. Illnesses may be mild to severe with the possibility of meningitis, pneumonia or severe dysentery that has been shown to be fatal in up to 55 percent of immunocompromised persons.[5] Adenovirus outbreaks are common in daycare facilities and schools in addition to other crowded sites such as military barracks and healthcare centers.[6]

While there is no cure for adenovirus infection, most illnesses are self-limiting. Infected individuals, however, may shed the virus in their feces and respiratory secretion, exposing others for weeks to months.[7] Infections are common globally where immunocompromised individuals, including infants and children, are more susceptible to adenovirus infection and more severe health outcomes.[6] Fatality rates may be as high as 60 percent in severely immunocompromised patients.

Adenoviruses are known to survive longer in the environment than other waterborne viruses, likely due to their hearty double-stranded DNA structure (most waterborne pathogens have either single-stranded DNA or RNA structures). Conventional UV disinfection inactivates viruses by damaging their RNA or DNA; however, the double-stranded DNA characteristic of adenoviruses enables the virus to be repaired once inside a host cell. Thus, adenoviruses have emerged as the most resistant waterborne virus to UV light (although they are more sensitive to inactivation to chlorine than other human viruses due to chlorine's nonspecific oxidation of nucleic acids and viral proteins).[6]

Improving UV efficacy

Numerous studies have shown 'resistance' of adenoviruses to UV disinfection. Most of these studies, however, have focused on the use of monochromatic, low-pressure UV light sources in the 254-nm emission range.[3] Low-pressure UV sources show a range of efficacy from 120 to 200 mJ/cm^2 for a four-log inactivation of adenoviruses (compared to 30 to 40 mJ/cm2 required for other waterborne viruses), where high doses are needed to overcome the DNA repair mechanisms of host cells.

A recent review questions the potential resistance of adenovirus to UV light.[3] While methods used to grow adenovirus inside host cells in laboratory flasks allow DNA repair to occur, researchers questioned whether or not the same repair scheme occurs in whole systems (i.e., humans or animals). In other words, does adenovirus DNA repair lead to infection in humans or is the condition simply a laboratory anomaly?

Either way, adenovirus DNA repair is not evident following inactivation with medium-pressure (MP) UV lamps. These UV lamps emit polychromatic light with several peaks in the optimal germicidal range.[8] Recent research using polychromatic UV light sources have shown increased efficacy in adenovirus inactivation, given that they damage more than just the viral DNA but also vital proteins. In addition, high-intensity pulsed UV lamps are being tested against adenoviruses. MP and pulsed UV have been found to achieve the target four-log reduction of adenoviruses at doses of 40 mJ/cm^2. [3]

A UV renaissance

Use of ultraviolet lamps for water disinfection is not new, dating back to Westinghouse's production of UV lamps for water treatment in 1909, followed by the first municipal treatment plant adopting the technology in 1916.[9, 10] Although a widely used technology in POU water treatment systems, UV disinfection is used by only one percent of the 200,000 community water systems in the US and Canada, although applications are rapidly expanding. The world's largest UV water treatment facility is now under construction in New York City and scheduled for operation sometime in 2012. This facility is designed to disinfect up to 2.4 billion gallons of water per day utilizing state-of-the-art design.[11]

In terms of future strategies for UV disinfection, Eischeid *et al.* (2011) call for additional research to determine the molecular mechanisms of DNA inactivation, and to evaluate infectivity of UV-treated viruses in whole animal models, beyond the cellular-based laboratory assays. The authors point out that no research has been published evaluating adenovirus infectivity in whole animal models, a method that proved to be necessary to show that *Cryptosporidium* was highly susceptible to UV disinfection.[12] Previous studies with *Cryptosporidium* using cell-based laboratory assays gave the false impression that the waterborne pathogen was resistant to UV. In the end, UV-disinfectant technologies have traveled a bumpy road toward effective use in drinking water treatment, but the future promises to include more widespread applications.

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