

Potential benefits and harms of the use of UV radiation in transmission of tuberculosis in South African health facilities

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Abstract

The incidence and prevalence of transmitted *Mycobacterium tuberculosis* have risen very rapidly in modern society. Environmental control measure such as ultraviolet radiation has been introduced in various health care facilities. This preventative measure has been extensively explored in the medical, legislative and public forums. However, the guidelines and manufacturer's claims have created controversies, in terms of prevention of cross-transmission of *M. tuberculosis* in health care facilities. In this article, the authors reviewed the overall benefits and harms associated with the use of ultraviolet radiation in the prevention of *M. tuberculosis* transmission. The author concluded that there are still existing gaps in proving beyond any reasonable doubt that ultraviolet radiations absolutely prevent the spread of *M. tuberculosis* in South African health facilities.

Introduction

Tuberculosis (TB) remains one of the leading infectious diseases worldwide, despite the efforts to identify and treat infected patients. It is a serious public health threat in developing countries such as South Africa, especially among the destitute, groups of the migrants, inmates in correctional services inmates and people infected with the human immunodeficiency virus (HIV). Environmental measures have gained much more interest in the prevention and control of TB transmission.¹

TB is transmitted from person to person by tiny droplet nuclei containing the acid-fast bacilli called *Mycobacterium tuberculosis*. People who are infected, or are on multidrug resistance (MDR) or extensively drug-resistant (XDR) treatment, to the next person or to the surrounding area or room, cough up this bacterium on air. So, the longer the susceptible or uninfected person share space or air infected with these bacilli, the greater the chance of infection.¹

TB has experienced a resurgence in recent years and is often a hallmark of HIV/AIDS, causing those infected not to seek medical attention because of social stigma. The new problem which has hit the world, including South Africa, is the emergence of multidrug resistance (MDR) or extensively drug-resistant (XDR) forms of TB.¹ This has placed a new emphasis on preventing the spread of TB from patient to susceptible individuals.

The World Health Organization (WHO) has put a mandate, especially in developing countries such as South Africa, to improve infection control in hospitals, as facilities risked becoming the breeding ground for XDR-TB if patients and staff are not adequately protected from those infected.² To control the spread of TB infection, some facilities are implementing other control measures such as environmental measures (filtration, ventilation, UV radiation) to halt the rate and spread of TB infection.³ In these instances, the primary objective is to prevent the spread of TB by protecting susceptible people from inhaling airborne particles generated by infectious individuals using environmental control measures.⁴

Ultraviolet radiation is one of the commonest environmental control measures that can be used to kill infectious microorganisms such as TB. UV lamps are cost efficient, accessible and, installation friendly and therefore they are strongly recommended by various health government agencies worldwide.⁴

Environmental control measures of ultraviolet radiation can only be enhanced by other factors such as active detection, prompt treatment and tracking of cases. Research has shown that in developing countries such as South Africa where tagging and tracing of cases is difficult, UV sterilization and other environmental control measures can successfully be used to protect the spread of TB.⁴

The first report of the use of ultraviolet radiation was in 1930, this was proved effective in sanitizing air and killing harmful bacteria and microbes, including TB. In all these patients, it was UVC, which was used.⁵ Sunlight as it was long reported, provided irradiation at ground level longer wavelength UVA and UVB, which are used by holidaymakers for obtaining a suntan. While UVA and UVB have their own problems such as the possible eventual emergence of skin cancer, UVC is highly dangerous to both the eyes and the skin, but studies have shown that humans are protected by the solar radiation of the ozone layer.

The commonest method of ultraviolet radiation used in most facilities is using UV germicidal lamps with low-pressure mer-

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cury that can release radiation at 254 nanometres. They are usually suspended above the average height of people (2.7 meters high) in an area or within a channel of recirculating systems. The use of germicidal UV lamps has long remained to sifter air that run-in health care facilities for many years. To a certain degree, germicidal UV radiation remained to be the most effective method to control the circulation of airborne infectious elements. However, there is inadequate proof and information on which to base a decision that the use of UVGI is the standard golden technology method for preventing tuberculosis transmission.⁶

Numerous studies have been done, to investigate the effectiveness of UV germicidal radiation for various microorganisms in a range of temperature and humidity conditions.^{7,8} Of all these studies, only a few have appraised the practical application of direct room UV germicidal radiation in health care facilities.⁹ Majority of related evidence comes from investigations done mostly under simulated conditions. In most

instances, majority of these studies, served as the basis for many controversial guidelines regarding the use of UVGI systems to protect health care providers and the public from the spread of TB infection.⁹ Therefore, this study review explored the potential benefits and harms of the use of germicidal ultraviolet radiation used in South African health care facilities for the prevention of transmissible TB infection.

Transmissible infectious agent such as *Mycobacterium tuberculosis*

Most of the transmissible infectious agents are distributed into air, through deep coughing or sneezing.¹⁰ Though the infectious agents are usually suspended in the air, whether the suspension lasts or not depends on various factors such as the particle size, velocity, force of sneezing or coughing, the particle density and the ability of the microorganism itself to cause the infection once it is in contact with the susceptible individual. And also, environmental factors such as room humidity and rate of air flow have a significant impact on fast tracking or slowing the transmission of an infectious agent. Roy and Milton,¹¹ proposed that the spread of transmissible infectious agents relate to the size of the microorganisms in droplet nuclei or to size of the droplet itself. The size can vary from compelled breath of floating airborne, such as *M. tuberculosis*, to privileged breath transmissions, such as measles, *Haemophilus influenza*, and *Varicella zoster* that can take the benefit of exceptional environmental and clinical circumstances that allow dissemination over a long distance. The droplet nuclei containing *M. tuberculosis* pathogenic agent can travel via air currents, aided by the ventilation system, and be spread over a wide area like any other airborne infectious agent. The disease-causing organism then is inhaled and cause infection. Hypothetically, pathogen-laden droplets expelled during certain procedures such as suctioning, endotracheal intubation and induction of cough by physician might result in droplet nuclei travelling faster and further distances and reach deeper into the respiratory tract of susceptible person's easily.¹² However, natural infectivity of a nuclei droplet requires relatively shorter distances of 1 to 2 meters. Usually the respiratory droplets containing infectious agents travel quicker and straight from the respiratory tract of the contagious person to another susceptible person through deposition on mucosal facades of the recipient.¹² The distance that droplets travel depends on the velocity and the mechanism by which respiratory droplets are driven

from the source, the density of respiratory secretions, environmental factors such as temperature and humidity, and the ability of the pathogen to maintain infectivity over that distance. In dry air, droplets evaporate quickly, shrink in size, and fall to the relatively slowly. The changing size of a droplet affects how it responds to airflow patterns and how quickly it settles.¹²

Crucial features of infectious agents in health care facilities

Ordinary forces such as heat resistance due to air temperature differences, the wind, or mechanical fans, can create air flows that move air from one room to another. Different factors affect how the transmissible agents can be spread from one person to the other, across the environment and in between the inanimate objects.¹³

For example, in a hospital setting, patients lie in bed much of the time. The direction of an exhalation jet from a standing or seated person is much stronger than that generated from lying patient (especially when facing up). The general upward cloud generated by a seated or standing person differs completely from a sleeping patient. Consequently, the differences between the behaviours of breathing course in hospital and other indoor environments are expected.¹⁴ Similarly, exhalation in a horizontal positioned or standing patient can be influenced by various factors such as a way of release of contamination and the heat generated by the human body or other sources. Less than 5 µm droplet nuclei exhibit a settling velocity of less than 1 m/h in the normal air flow in a hospital ward. Clinically, it is essential to make differences among short-series airborne infections pathways between individuals (generally less than 1 m apart) and long-range routes within a room, between rooms or distant locations generally distances above 1 m.¹⁴ Some authors reported that there are set droplet size definitions:^{13,14} such as large droplet which has a diameter above 60 µm, small droplet that has a diameter less than 60 µm and usually droplet nuclei that has a diameter less than 10 µm. Long range transmission becomes likely feasible when the droplets of infectious material are sufficiently small to remain airborne almost indefinitely and to be transmitted over longer distances.

Is UV radiation effective at killing TB bacteria?

The ensuing issues most commonly

considered in determining whether UV radiation will kill a microorganism are as follows: the microorganism type; the exposure radiation dose, and the moisture content present in the air.

A study has shown that UV radiation can be able to speedily destroy airborne bacteria and viruses, but it is not as much effective against fungal and bacterial spores.¹⁵ TB causing bacteria are more resistant to UV than a few others, but they are not as tough as spores. UV radiation does not infiltrate fine through matter, thus, bacteria conceded in bulky units of dried sputum, for example, might be protected from the sanitizing radiation. However, these larger particles do not remain suspended in the air for very long nor do they reach the lower lung if inhaled, and therefore do not pose as great a risk of infection as do smaller, more UV-sensitive particles.¹⁶

According to literature, the dose of UV radiation must be adequate enough to kill the TB bacteria.¹⁷ This can be accomplished with lamps of the accurate wavelength and intensity and by exposing the bacteria for over a long period of time. Moreover, there must be good mixing between the treated upper area and the air lower in a room where people are.¹⁷ In a manner of doing so, contaminated droplets are shifted into the irradiated sector and the disinfected air dilutes the contaminated lower air. Convenient ceiling fans can be used to intensify circulation of air.

The bactericidal efficiency of UV radiation at indoor temperatures have been shown to be intensified by relative humidity at 70%. This moisture content is not common in air-conditioned infrastructures or through the frostier months of the year when the airborne transmission is more likely. However, if additional humidity is problematic, air disinfection must be totally reliable on other practices of environmental control, such as amplified ventilation or duct irradiation.¹⁸

In developing countries such as South Africa, it has been realised that hospitals are still being designed the way they were two decades ago and the TB pandemic of today is not being addressed in the design of new facilities.^{19,20} To address this issue, a new facility was founded (known as airborne infections research (AIR) a Mpumalanga provincial TB referral hospital, under joint collaboration with Medical research council (MRC), Council for scientific and industrial research (CSIR) and overseas consultants) where primarily, guinea pigs were used as human surrogates, in conditions closely monitored and controlled to resemble humans in their response to TB infection.

A study was done by AIR team to investigate the effectiveness of UV radiation in preventing the spread of the TB disease, especially MDR and XDR variants. In their findings, they established that upper room germicidal UV air disinfection with air mixing was exceedingly effective in decreasing tuberculosis transmission under ambient hospital conditions. This finding supported using both a total fixture output of 15-20 mW/m³ and a total room volume or average whole-room UV irradiance (fluence rate) of 5-7 $\mu\text{W}/\text{cm}^2$.²⁰ Though inspiring results were accomplished concerning use of upper room UVGI, working in close proximity to room occupants still posed a significant risk, since exhaust air from the ward accurately reflected the average infectiousness of well-mixed ward air, it did not reflect transient higher local concentrations before the mixing occurs. Therefore, there is still a terrible need for regular maintenance of upper room UVGI equipment to ensure the predicted equivalent air changes.

The technological applications required for disinfection of air in health care facilities

The most widely used application of UVGI is in the form of player of UV passive upper-room fixtures containing UVGI lamps that provide a horizontal layer of UV energy field above the occupied zone.²¹ These fixtures are designed to inactivate bacteria that enter the upper irradiated zone, and their efficacy is highly reliant on, among other factors, the airflow field conditions in the room. The survival probability of bacteria exposed to UV irradiation depends on the susceptibility of the target microorganism and the dose and duration of UV-C to which it is exposed.²¹

Upper-room air lamps

Lamps used to produce UV-C are located relatively high up in the room (average 2.7m high), to prevent exposure to occupants by a specially designed fixture. There are basically two designs: a “pan” fixture with UVGI unshielded above the unit to direct the irradiation upward, and a fixture with a series of parallel plates that direct the irradiation outward while preventing the light from reaching the eyes or unprotected skin of room’s occupants. Germicidal activity is dependent on air mixing via convection between the room’s irradiated upper zone and the lower patient care zones.²² This was confirmed in an investigation that involved the installation of upper-room UVGI units and evaluation of these units’

impact on culturable airborne bacteria. More than 90% of the bacteria detected were inactivated; however, the rate was lower for more resistant bacteria and fungal spores. That investigation also clearly demonstrated that room air must be mixed for UVGI to effectively inactivate microorganisms. When warm air entered the room via a duct close to the ceiling (which can occur in the winter when the heating system is turned on), the warm air simply “rested” on the much cooler air below, and the efficacy of the UVGI system was dramatically diminished because the microbes did not move up for exposure to the UV-C irradiation. No mixing fans were turned on during the experiment, but moderate ventilation was present.²²

The cleanliness of UV light bulbs and age of UV lamps should be checked periodically (approximately every 6 months) to ensure sufficient UV light intensity for germicidal activity (UV-C). The intensity of germicidal wavelength light decreases with age, and bulb ratings (hours of use) may vary by manufacturers specifications.^{22,23} Upper room UVGI is often seen as a cost-effective measure to supplement the general ventilation system in a room; however, the combination of the general ventilation system and the UV lamps might not necessarily be implemented correctly within a room. For example, if the ventilation rate is too high the particles may not be complete inactivation, or if the ventilation system does not provide good mixing within the room, airborne particles containing microbes might not even be exposed to the UV-C irradiation.^{22,23}

A well designed upper-room UVGI system may effectively kill or inactivate most airborne droplet nuclei containing *Mycobacterium* spp. if designed to provide an average UV fluence rate (*i.e.* irradiance from all angles that is incident on a small region of space: a more accurate term than “UV dose”) in the upper room in the range of 30-50 $\mu\text{W}/\text{cm}^2$, provided that the other criteria stipulated in the CDC’s TB guidelines are met. The fixtures should be installed to provide as uniform a UVGI distribution as possible in the upper room.²³ Schafer *et al.*²⁴ developed a method to measure fluence rate and used it to verify that this rate varied as much as 3-fold in a typical room, depending on proximity to the lamp, and found that lamp failure was common. This reinforces the need to monitor the efficacy of the lamps used in UVGI fixtures. Under experimental laboratory conditions with mechanical ventilation rates of up to 6 air change per hour (ACH,) the rate at which microorganisms are killed or inactivated by UVGI systems appears to be

additive with mechanical ventilation systems in well-mixed rooms.

Escombe *et al.*²⁵ recently investigated impact of upward-facing UV light fixtures installed in ceilings of a negative-pressure TB isolation ward and ceiling mounted air ionization fixtures in an animal enclosure chamber, using a guinea pigs air sampling model that involved exposure of the animals to exhaust air from the isolation ward. With this animal model, 35% of controls exposed to untreated exhaust air from the TB ward developed TB infection, whereas frequency was reduced to 14% and 9.5% with the use of an ionizer and UVGI, respectively. They concluded that “provided” there is adequate mixing of room air, an upper-room UVGI fixture is an effective, low-cost intervention for use in TB infection control in high-risk clinical settings.²⁵

In South Africa, UVGI lamps are used in hospital wards waiting areas and other environments in one of two ways.²⁶ It can be fitted into an air extraction system which already has very effective filtering or it can be used in light fittings to irradiate the upper part of a room.²⁷ The filtration method only works where the buildings have been designed for this task and this is not usually the case of makeshift TB wards established as the pandemic spreads during an outbreak. The UV lamps are safe as they are placed out of sight in the ducts and calculations can be made on the UVGI irradiance required to kill 90% or more of the TB bacteria.²⁷ Most of the time the clean air is ducted to the outside or returned to its site of origin to remove any residual bacteria on a second pass. The upper light fittings are a cost-effective way of controlling the spread of bacteria in an already constructed ward or waiting room.²⁷

What are critical factors to be considered in measured UVGI efficacy?

According to the literature,²⁸ the efficacy of UVGI is affected by factors such as optimal temperature, relative humidity, and lamp output. There is substantiate evidence showing that the effectiveness of upper-room UVGI systems decreases as relative humidity increases. In lieu of optimum efficiency, relative humidity should be controlled at 60% or less when upper-room UVGI systems are fitted. The optimal temperature should be maintained at a range of 20°C and 24°C.²⁸ While on the hand, in the experimental upper-room UVGI systems used in rooms with aerosolized bacteria (including surrogates of *Mycobacterium tuberculosis*) the higher the UV fluence rate

produced in the upper air, the greater the effectiveness of the system.^{21,29} Based on results of experiments with upper-room UVGI systems and aerosolised bacteria in bench-scale reactors, it is apparent that the greater the UV fluence rates in the irradiated zone, the more effective the system. However, there appears to be an upper threshold after which an increase in UVGI does not directly correspond to an increase in the system's ability to kill or inactivate microorganisms.²⁹ This was observed in a study, where, decreased effectiveness of the UVGI system was noted when the UV fixtures were placed on only one side of the room. The findings were consistent with other studies done elsewhere in the world,^{21,23,29} which reported that a wider, distribution of low-radiance UV lamps was more efficient compared with the use of one centrally located high-radiance UV lamp. This suggests that upper room UVGI systems should be installed to provide the uniform UVGI distribution only in the upper air.

In experimental conditions

Most of the experimental studies that form the basis of the irradiance guidelines were primarily studied on single cells aerosolized bacteria in deionized water. Because of a lack of covering mucus layer, bacteria seem to be more sensitive to UVGI compared to *M. tuberculosis* droplet nuclei from contaminated host.^{29,30} The killing or deactivation of 63% of droplet nuclei in a room by UVGI is equivalent to 1 air changes per hour (ACH) in terms of reduced total droplet nuclei by a method other than mechanical ventilation.

In Air Handling Units (AHU) including in-duct applications

UVGI lamps can be fitted in several locations in an air conditioning system. One likely location is exclusive air handling units (AHU), more especially in front of the cooling coils and drip pan. There are certain reports that indicates that this arrangement results in energy preservation and save costs, but there is still a need to reproduce and validate this statement. Some manufacturers of these systems have also made claims of reduced incidence of healthcare-associated infections with the use of UVGI in air handling units. Majority of the published investigations rely on the environmental surface or air sampling cultures or laboratory-based animal studies for inferential support. Some literature claims of reduced healthcare-associated infections from air handling units-installed UVGI in health care facilities are emerging off-lately. There is some evidence of fewer complaints

which relate to indoor air quality in buildings with systems containing UVGI inside air handling units.^{30,31} However, there is an existing body of evidence demonstrating a significantly lower concentration of fungal spores on a floor of a building with an in-duct UVGI system compared with a floor in the same building without such system.³¹ The number of spores found in the building here of similar to those from insulation material in the ventilation ducts. Thus, the authors concluded that few spores from the outdoors distributed throughout filters in the air handling units developed when the cooling systems was switched either on or off. Remarkably, they noted that as a result, they cannot conclude that the UV-C radiation had a direct effect on spores in the air stream. The effectiveness of UV-C lamps seemed to be localised because visual inspection indicated that there was conspicuous fungal growth in the downstream duct insulation lining.³¹ UV lamps also can be placed inside supply or return air ducts to disinfect the air before it is supplied to an occupied space or when re-circulated.

In air cleaning

UV irradiation on its own does not clean air. If accompanied with air cleaning property agents such as aerosols, most of the microorganisms survive, though with limited infectious ability or virulence. Although UV potentially can destroy allergenic sites on the surface of a microorganism, this ability has yet not been quantified to the maximum satisfaction. Bacterial inactivation studies using BCG; a strain of *Mycobacterium bovis* have estimated the effect of UVGI as equivalent to 10 to 39 ACH.³² However, another study suggested that UVGI may result in fewer equivalent ACH in the patient care zone, especially if the mixing of air between zones is insufficient. The use of fans or condition system to generate air movement and good mixing might increase the effectiveness of UVGI by ensuring exposure of airborne microorganisms to the light energy for a sufficient length of time.

Potential benefits of UVG radiation at killing TB bacteria in a health care facility

Majority of people work in office buildings with closed exterior shells, where highly automated heating, ventilation, and air conditioning systems run by operators, with controlled indoor environments. However, there are health related problems reported associated with these automated systems of

which their resolution can maximise the health benefit of approximately 15 million workers and can save the economic costs of approximately 5-75 billion per year.³³

The highly effective use of upper room UVGI is to prevent the transmission of *Mycobacterium tuberculosis* (MTB) in health care and other congregate spaces, especially in high burden and resource constrained environments. The high volume of mechanical ventilation air changes per hour [ACH] recommended for the prevention of airborne infection is often not feasible in these settings.³⁴ Facilities in suitable climates often depend on natural ventilation, which can be highly effective in well-designed buildings under optimal outside conditions, but can also be inadequate when conditions are suboptimal, and at night when windows may be closed for thermal comfort, pest control, or security.³⁴ In cold climates, natural ventilation is often not a practical option, but even in hot climates, as air conditioning becomes more widely used for thermal comfort, windows are usually closed. In these and other settings, upper room UVGI, often combined with natural or mechanical ventilation, may be the most cost-effective method for providing effective air disinfection.³⁴

In order for UVGI to be effective, the aerosols containing *M. tuberculosis* (droplet nuclei) must remain airborne and must obtain a sufficient UVG radiation dose to be killed or inactivated. Droplet nuclei have negligible settling velocity and will be dispersed with air currents.³⁴ Because of this, the UVGI radiation is highly recommendable for the guidelines to reduce airborne TB transmission in health care facilities.^{33,34}

UVG radiation is effective in killing or inactivating airborne *M. tuberculosis*. Naturally, the optimum wavelength for UV germicidal radiation is 254 nm in the UV-C range.³⁵ UVG radiation can be found in exhaust ducts, in upper-air irradiation systems, or in portable room air recirculation systems. This method can be used as a matching option in healthcare facilities, for example, emergency rooms, large waiting areas, and other enclosed spaces, where ventilation cannot be effectively protective and where extra protection is necessary. However, this method does not provide additional air and does not substitute ventilation systems.³⁵ Research studies have established experimental TB hospital wards for studying TB transmission in a controlled environment both in Peru and South Africa.^{17,20,25,27,36} The manufactured TB ward consisted of the use of UVG radiation fixtures, masks on patients, room air ionizers, room air filtration machines, and

inhaled antibiotics. The effectiveness of upper room UVG radiation with air mixing in an MDR-TB referral hospital was tested. The study's findings confirmed the high effectiveness of upper room UVG radiation with air mixing under realistic condition with its own defined parameters. The study has greatly shown that commercially available upper room UVG radiation fixtures all generate useful germicidal irradiation with varying efficiency. Similarly, another animal study done under real hospital conditions demonstrated that the risk of tuberculin skin test (TST) conversion was 4.9 times higher in the control group compared with upper-room UVGI group.^{25,27,36} Therefore in a surrogate and controlled environment, exposure of UVG radiation can effectively kill *M. tuberculosis*.

Potential harms in humans because of exposure to UVG in a health care facility

The automated devices installed and

maintained in health facilities such as UVG radiation and lamps are potentially hazardous causing problems like dermatosis or photokeratitis if improperly designed or fitted.³⁷ Even in South African health facilities especially Tshwane district health facilities, small pockets of complaints and cases are continually slightly encountered, though not yet reported. The evidence of reported studies with potential hazardous and harmful effects as a result of exposure to UVG radiation is shown in Table 1.³⁸⁻⁴⁶

These studies have shown that adverse effects are limited to the skin and eyes. Exposure to UVG radiation is in the UV-C region of the radiation spectrum. UV-C may cause reddening of the skin and conjunctivitis (a feeling of sand in the eyes), but scanty evidence of long-term effects such as skin cancer or cataracts in humans.⁴⁷ Since UV-C is absorbed in the outer layers of the skin and eyes, the irritation produced by overexposure is superficial. Short-term overexposure may result in photokeratitis and/or keratoconjunctivitis. Keratoconjunctivitis may be debilitating for several days but is

reversible. Because these effects usually manifest themselves 6h to 12h after exposure, their relationship to UVG radiation exposure most of the time it is overlooked. This is mainly because; it is assumed that, the effects of UVG radiation usually disappears within 24 hours without lasting effects. Therefore, there is a need to establish whether acute eye and skin conditions because of exposure to UVG radiation do not progress into chronic conditions such as skin cancer and cataracts and other eye conditions.

Conclusions

Although numerous studies address the efficacy of UV-A, UV-B and UV-C with the latter equivalent to UVGI, there remains a lack of growing evidence of epidemiologic data in resource constraint facilities in South Africa demonstrating that irradiation prevents the spread of infectious agents such *M. tuberculosis* endemic to health care facilities. In most of the health facilities in

Table 1. Studies reported on harmful effects of UVGI exposure.

Author	Study Location	Year of publication	Journal Name	Key Findings: Potential Harms in Humans
Murray WE ³⁸	CDC: NIOSH	1990	Health Phys	Hazard to workers in a mycobacteriology laboratory, 76 were found to have a high NIOSH exposure limit to UVGI, with a potential harm to eyes and skin.
Nardell EA ³⁹	-	2008	Public Health Reports	Cell of the cornea when exposed to greater UV radiation can result in injury
	-	2008	Public Health Reports	Photodermatitis and more commonly photokeratoconjunctivitis are common if exposure to UVGI is over a short term.
	-	2008	Public Health Reports	A questionnaire regarding eye and skin irritation was administered to a total of 3,611 staff and homeless study subjects. Among these subjects, there were 223 reports of eye or skin symptoms
Purcell JJ Jr and Krachmer JH ⁴⁰	-	1976	N Engl J Med.	8 workers developed photokeratoconjunctivitis from an inadvertent 20-minute exposure to lower room UVGI in an operating room.
Talbot EA <i>et al.</i> ⁴¹	Botswana	2002	Int j tuberc lung dis	Two nurses, a housekeeper experienced eye problem, and facial skin peeling from exposure to unshielded 36-watt UVGI lamp turned on accidentally.
Trevisan <i>et al.</i> ⁴²	Italy	2006	Photochem Photobiol	26 Italian medical students exposed to a bare bulb direct lower room germicidal UV source for 90 minutes during an autopsy demonstration. Both reported eye and skin symptoms.
Zaffina <i>et al.</i> ⁴³	-	2012	Photochem Photobiol	A case report that describes an accidental exposure of two health care workers to ultraviolet radiation produced by a germicidal lamp in a hospital pharmacy
Brickner PW and Vincent LR ⁴⁴	USA	2013	Photochem Photobiol	For all those working in the field of UVGI, safety issues must be a concern because when UVGI fixtures are placed improperly, or precautions ignored, room occupants are placed at risk of photokeratoconjunctivitis and photodermatitis.
Moss C. and Seitz TA ⁴⁵	USA	1991	Appl. Occup. Environ. Hyg	Employees complained of eye and skin irritation that was worse during the workweek, but better over the weekends despite outdoor solar exposure.
Tai-Shion Lee ⁴⁶	USA	1996	Chest	Two persons had red, gritty eyes with blurry vision, and one person had severe ocular discomfort with redness, watering, and blurred vision that lasted 8 h.

South Africa, the use and installation of UVGI is often overlooked as an engineering innovation than a curing effect, which is always accompanied by ignored medical side effects.⁴⁸ Therefore, the properly installed upper room UVGI application depends strongly on sufficient exposure of microorganisms to UVGI, which can occur if there is good mixing of upper and lower air in the room or area where installed. Furthermore, there are several industrial claims suggesting that UV related systems will protect occupants against emerging diseases such as *M. tuberculosis*. These claims have not been substantiated by the existing data, and need to be evaluated against many variables. Although experimental studies have proved beyond any reasonable doubt that under controlled and maintained conditions the spread of *M. tuberculosis* can be prevented using UV radiation, the key question remains that there is a need to demonstrate the absolute role of UVGI in the background of the pyramid of controls to prevent healthcare-associated TB infection.

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