REVIEW ARTICLE

# Efficacy, Safety, and Application of Ultraviolet Radiation for Disinfection in Dentistry: A Systematic Review

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## Abstract

**Background:** New antimicrobial procedures are of significant importance to emerging species of bacteria and viruses. The objective of this systematic review study was to identify the efficacy, safety, and application of UV light in the disinfection of dental environments, instruments, and materials.

**Methods:** In this systematic review article, the authors performed an electronic search of Google Scholar, Pubmed, and SCOPUS databases to retrieve related English-language articles published between the years 1990 and 2020. At first, the selected articles were reviewed by screening their titles and abstracts and ultimately by full text.

**Results:** 35 articles were considered relevant and included in this study. Fifteen studies were related to the antibacterial efficacy of UV radiation on various bacterial, fungal, and viral species. Two studies applied UV irradiation for the disinfection of titanium implants. Sixteen articles suggested the application of UV radiation for disinfection of dental impressions, toothbrushes, N95 masks, removable prostheses, acrylic resins, and surfaces. Furthermore, one study strongly suggested using eye protection appliances while working with UV radiation, and one study claimed that UVB radiation led to oral and skin cancer while this risk is higher for oral cancer.

**Conclusion:** UV radiation with a specific dose and a duration effectively kills viruses, bacteria, and fungi for disinfection in dental procedures, which includes dental tools and materials such as toothbrushes, dental implants, impression materials, removable dentures, and dental environment. However, the principles of protection are emphasized to reduce its harmful effects on the eyes and skin.

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**Keywords:** Dental equipment, Dental instrument, Dental office, Disinfection, Ultraviolet rays

## Introduction

Since dental offices produce a high amount of aerosol during routine dental procedures, contamination of the dental environment, dental tools, and materials has been a major concern for patients and dentists. Contaminated dental instruments and materials might transmit microorganisms if dentists do not follow infection control protocols well. In addition, blood-borne, air-borne, and infectious diseases spread via saliva have a high risk of transmission to patients in dental environments.[1] The advent of the COVID-19 pandemic in 2019 and the lack of effective vaccines have increased the importance of research on appropriate disinfectants to control virus prevalence.[2]

Various approaches have been reported for the disinfection of dental instruments, each of which can have limitations despite some advantages. All disinfection strategies cause biological effects and chemical reactions to some extent. Cytotoxicity is essential to measure when developing a potential antimicrobial material.[3] Furthermore, chemical reactions with metal tools and equipment might cause damages like corrosion and rust.[1]

Ultraviolet (UV) is the region of the electromagnetic spectrum between visible light and X-rays with a wavelength of 10 to 400 nm. In other words, its energy is less than X-rays but more than visible light.[4] UV rays are divided into three types: UVA (wavelength: 320-400 nm), UVB (wavelength: 280-320 nm), and UVC (wavelength: 200-280 nm).[5] Overexposure to UVA and UVB negatively affects skin melanocytes and causes premature aging by releasing melanin. It is noteworthy that UVB is the radiation overexposure t that causes severe skin inflammation.[6] UVC, which includes rays with a wavelength of less than 280 nm, is the optimal radiation for antibacterial purposes. The direct interaction of microorganisms, including bacteria, viruses, fungi, and UV irradiation results in the breakdown and destruction of the cell's genomes of either DNA or RNA.[7] After UV irradiation, the microorganism's DNA sequence produces a pyrimidine dimer, which interferes with DNA replication and leads to nucleic acid degradation and cell destruction.[8] The highest UV uptake by DNA of microorganisms has been reported to be at a wavelength of 254 nm.[7]

In addition to therapeutic applications of UV radiation in root canal therapy, in dental clinics, UV rays are widely used to decontaminate the environment, surfaces, settings, instruments, and impressions to limit the transmission of pathogens via different person-person routes. UV radiation can also be used to disinfect the implant surface in order to prevent peri-implantitis.[9]

Because dental procedures pose a high risk of transmission of severe disease, in this study, we reviewed articles related to UV disinfection in three groups: efficacy, safety, and application.

## Methods

**Search strategies:** The PICO elements for this study are: P (problem): Contamination of dental lab, dental office, dental environment, dental instruments I (intervention): UV light C (comparison): placebo (not using UV light) O (outcomes of interest): efficacy, safety, and applications.

Based on the main approach of the present study, for a comprehensive review, the authors collected the evidence and investigations related to the efficacy, safety, and applications of UV radiation for disinfection in the dentistry field. The authors searched for articles in Google Scholar, PubMed, and SCOPUS databases from 1990 to 2020 and, in the first step, they selected articles by reviewing their titles and abstracts. Ultimately, the authors considered the full text of the articles. The search strategy was a combination of Keywords included: ('dentistry' OR 'dental medicine' OR 'dental system' OR 'occupational dentistry' OR 'paediatric dentistry' OR 'paedodontics' OR 'pathology, oral' OR 'pediatric dentistry' OR 'pedodontics' OR 'practice, dental' OR 'specialties, dental' OR 'state dentistry' OR 'laboratory' OR 'dental laboratory' OR 'environmental laboratory'OR 'laboratories' OR 'laboratories, dental' OR 'laboratorium' OR 'laboratory animal science' OR 'laboratory functioning' OR 'laboratory profile' OR 'laboratory science' OR 'laboratory service' OR 'laboratory technic' OR 'laboratory work' OR 'dental facility' OR 'dental facilities' OR 'dental office' OR 'dental offices' OR 'facility, dental' OR 'dental device' OR 'dental devices' OR 'dental devices, home care' OR 'dental equipment' OR 'dental equipment (physical object)' OR 'dental high speed equipment' OR 'dental high-speed equipment' OR 'dental high-speed technique' OR 'dental instrument' OR 'dental instrumentation' OR 'dental instruments' OR 'equipment, dental' OR 'home care dental devices' OR 'dental environment') AND ('ultraviolet radiation' OR 'uv' OR 'uv radiation' OR 'light, ultraviolet' OR 'radiation, ultraviolet' OR 'solar ultraviolet simulator' OR 'ultra violet' OR 'ultra violet radiation' OR 'ultraviolet' OR 'ultraviolet light' OR 'ultraviolet light radiation' OR 'ultraviolet photon' OR 'ultraviolet ray' OR 'ultraviolet rays' OR 'wood light' OR 'uv light') AND ('disinfection' OR 'desinfection')

Inclusion criteria for all articles included in this study were:

1. Studies published from the years 1990 to 2020,
2. Studies in English,
3. Articles (Original article) with a specific and relevant work method, clinical trials, and in vitro and in vivo studies.

Furthermore, exclusion criteria also included review articles, case reports, letters, questionnaires, and articles of poor quality.

First, the authors excluded the review articles, and articles not consistent with the objectives of this study. In the next step, they re-studied the abstract, and the full text of the articles, respectively, to identify and exclude studies that followed exclusion criteria or those that had a weak relationship with the objectives of the present study. Then, the studies selected by two examiners were evaluated in terms of bias risk using JBI (Joanna Briggs Institute) checklist. If there was any disagreement among the two examiners, the study was referred to a third party. After the final selection of studies, the required information was extracted and summarized using the designed extraction table in the

Excel software environment. Endnote X8 resource management software was also used to organize titles and abstracts and identify duplicates.

## Results

*Literature Search and Selection*

Figure 1 shows the process of searching the literature. First, 2000 articles were found and saved in Endnote X8 to remove duplicates. Then, after studying the titles and abstracts, the authors selected 150 articles,and a more detailed review by the evaluation team reduced the articles to 90. Next, the authors investigated the full text of these 90 articles, and finally, the authors selected 35 articles matched the inclusion criteria and followed the objectives of the present study as the final selection.

*Literature Quality Assessment*

To assess the risk of bias, the authors used the JBI checklist for qualitative research and quasi-experimental studies. Two studies were quasi-experimental and had no control group. In the JBI checklist, except for items 4 and 6, other items were established, while items 6, 7, and 8 were not also established in qualitative research. In general, this study had a relatively high risk of bias.

*Literature on the Efficacy of UV Radiation*

There were 17 papers in the efficacy field (2 in vivo studies and 15 in vitro studies) (Tables 1 and 2). Articles evaluated the efficacy of UV irradiation on bacteria including *Streptococcus mutans*, *A.actinomycetemcomitans*, *Streptococcus sanguinis*, *Pseudomonas gingivalis*, *Staphylococcus aureus*,

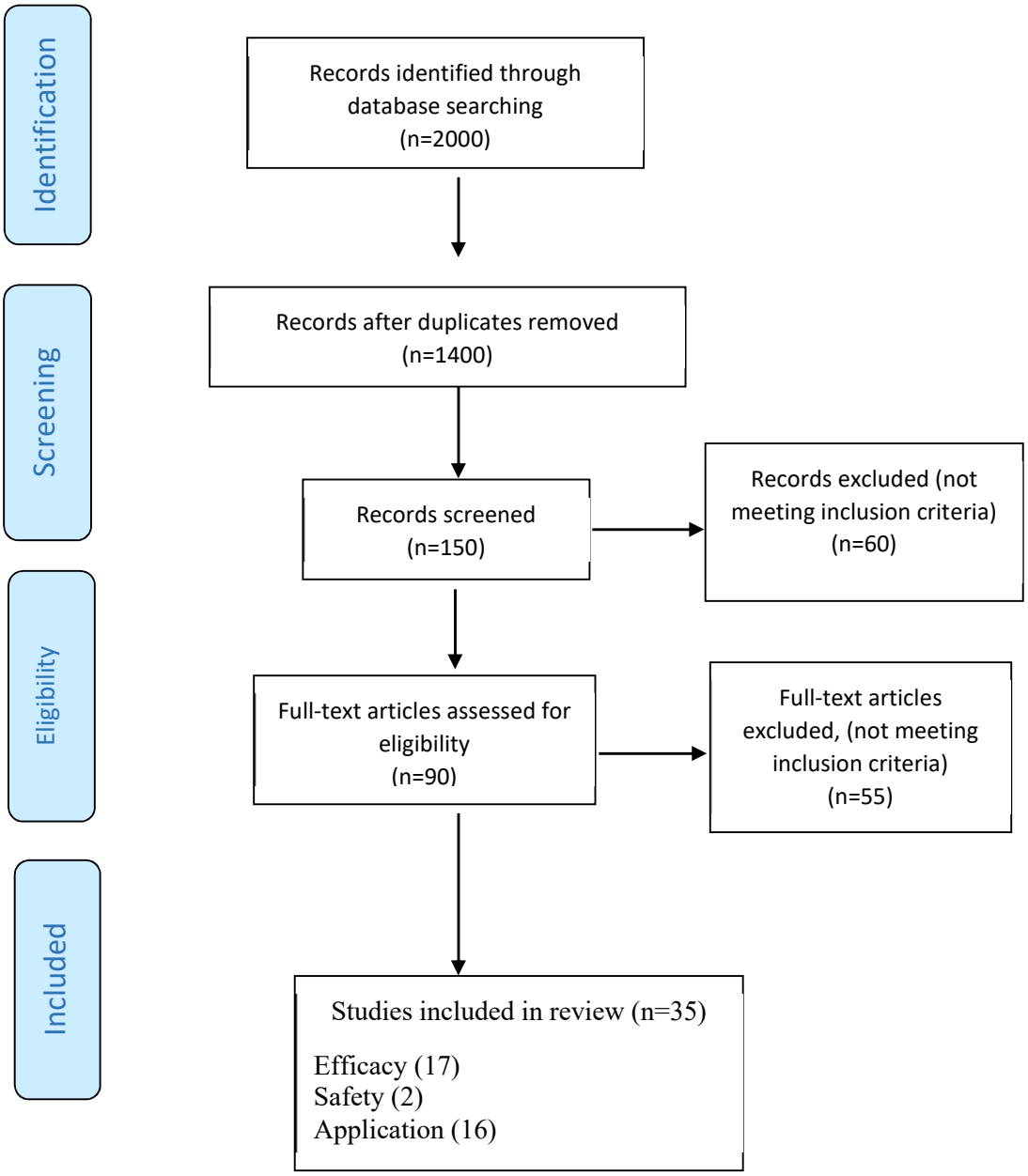


**Figure 1:** PRISMA flow process.

**Table 1:** Qualitative information obtained from reviewing articles in ultraviolet radiation efficiency.

| Author (year) | Type of study | Sample | Treatment Methods | Criteria |
|---|---|---|---|---|
| Svetlana Khaiboullina at al, (2020)[2] | in vitro | Virus HCoV-NL63 | Coating with nano-titanium ion+UV | Destroying: HCoV-NL63 |
| Ayuko Takada et al (2017)[8] | in vitro | Oral Microbes (*S.mutans, S.sauguinis, P.gingivalis, F.nucleatum*) | UVB-LED 310 nm | 1. Antibacterial effect 2. Toxicity (survival of oral epithelial cells) |
| Chun-Chieh Tseng and Chih-Shan Li. (2005) ([10]) | in vitro | Aerosols | UV Germicidal Irradiation (UVGI) | Disabling virus-containing aerosols |
| Taichi Tenkumo et al. (2020)[11] | in vitro | Bacteria on the surface of titanium | 1. Ag ion 2. UV-A rays 3. The combination of Ag ions + UV-A | Destroying: 1. *S.mutans* 2. *Aggregatibacter actinomycetemcomitans* |
| Hiroshi Ishida et al. (1991)[12] | in vitro | Fungi C.albicans *C. glabrota* *C. parupsilosis* *C. guilliermondii* | UV light (250,500,1000, 2000,3000, 8000 W/) | Destroying Fungi |
| Randold Binns et al. (2020)[13] | in vitro | *C. albicans* biofilm | UV light | Destroying *C. albicans* |
| A.R. Lemons et al. (2020)[14] | in vitro | *C. auris* *C. albicans* | Ultraviolet germicidal irradiation (UVGI) | Destroying: *C. auris* |
| Manuela Buonanno et al. (2020)[15] | in vitro | Coronaviruses in the air | Far-UVC light (222 nm) | Effect on beta HCoV-OC43 |
| Yoram Gerchman et al. (2020)[16] | in vitro | HCoV-OC43 | UV-LED 267 nm UV-LED 279 nm UV-LED 286 nm UV-LED 297 nm | Disabling: HCoV-OC43 |
| J. D. Druce et al. (1995)[17] | in vitro | HIV | UV light | Disabling: cell-free HIV and cell-associated HIV |
| JInshan He et al. (2008)[18] | in vitro | Microorganisms: 1. *S.aureus* 2. *C.albicans* 3. *T.mentagrophytes* | 1. Ag ion 2. UV + Ag ion | Destroying microorganisms |
| Erica Dorigatti de Avila et al. (2015)[19] | in vitro | Biofilm formed on titanium implants | UV-photofunctionalization | Comparison of biofilms in two groups with UV and without UV |
| Nagat Areid et al. (2018)[20] | In Vivo | Biofilm formed on titanium disks (Ti-6Al-4V) | 1. Coated titanium alloy (NC); 2. UV coated titanium alloy with (UVNC) UV; 3. Hydrothermally (HT) induced titanium alloy with TiO2; 4. Hydrothermally induced (UVHT) titanium alloy with UV with TiO2 | Destroying: S.mutans |
| Dubravko Risovic et al. (2014)[21] | in vitro | *C. albicans* | 1. UVC (254 nm) 2. UVA (365 nm) 3. violet) 406 nm) 4. violet/blue (420 nm) 5. full spectrum Xenon light (220-950 nm) | Destroying *C. albicans* |
| Christiane Silke Heilingloh et al. (2020)[22] | in vitro | SARS-CoV-2 | UV light | Disabling: SARS-CoV-2 |
| J. D. KRIESEL et aL. (1994)[23] | In Vivo | Herpes Simplex Virus | UV radiation | Diagnosis of Herpes |
| G. J. S. Taylor et al. (1995)[24] | in vitro | Bacteria in wounds and air | Ultraviolet C (UVC) | Destroying bacteria |

**Table 2:** The main results of articles in ultraviolet radiation efficiency

| | Author (year) | Results |
|---|---|---|
| 1 | Svetlana Khaiboullina at al. (2020) | UV irradiation for more than 5 minutes on Ticoated surfaces infected with the HCoV-NL63 virus leads to all viruses' removal. |
| 2 | Ayuko Takada et al. (2017) | - Irradiation with 310 nm UVB-LED at 105 mJ/cm2 showed 30-50% efficacy against oral bacteria,<br>- 265 nm UVC-LED (17.1 mJ/cm2) ultimately killed bacteria.<br>- 265 nm UVC-LED irradiation had cytotoxicity in contrast to 310 nm UVB-LED irradiation.<br>-*P.gingivalis* and *S.mutans* are sensitive to ROS produced following UV-LED radiation for 60 s<br>- *F.nucleatum* is not decreased by UVB-LED irradiation completely. |
| 3 | Chun-Chieh Tseng and Chih-Shan Li. (2005) | -The effect of UVGI on the virus depended on the type of nucleic acid of the virus.<br>-UV radiation for inactivating viruses with dsRNA and dsDNA was twice that of viruses with ssRNA and ssDNA. |
| 4 | Taichi Tenkumo et al. (2020) | Combined treatment of UVA with silver ion has a more significant bactericidal effect than UVA or silver ion radiation alone. |
| 5 | Hiroshi Ishida et al. (1991) | UV light (250 μW/cm$^2$) killed most microorganisms in 6 minutes, and at 8000 μW/cm$^2$ killed *C.albicans* within 2 minutes. |
| 6 | Randold Binns et al. (2020) | 300 seconds of 254 nm UV irradiation with an energy of 210 mJ/cm$^2$ leads to a 99.9% reduction in the viability of *C. albicans* cultured on PMMA samples. |
| 7 | A.R. Lemons et al. (2020) | UV radiation with an energy of 103-192 mJ/cm$^2$ is effective for inactivating *C.auris* but not efficient for inactivating *C.albicans*. |
| 8 | Manuela Buonanno et al. (2020) | Consecutive irradiation (222 nm) of far-UVC (~3 mJ/ccm$^2$/hour) on beta HCoV-OC43 for 8, 11, 16 and 25 minutes inactivates 90%, 95%, 99% and more than 99.9% of viruses. |
| 9 | Yoram Gerchman et al. (2020) | UV radiation with 267, 279, 286 and 297 nm wavelengths have the greatest effect on the HCoV-OC43 virus, respectively. Furthermore, wavelengths close to 260 nm have a greater effect on HCoV-OC43> T7> Enterovirus, Vesivirus> SARS-CoV-2> Qβ, Influenza> MS2> Adenovirus than 280 nm. |
| 10 | J. D. Druce et al. (1995) | For disabling cell-free HIV, samples must be exposed to UV in the UV chamber for 10 minutes. However, inactivation of cell-associated HIV requires more than 30 minutes of exposure. |
| 11 | He et al. (2008) | Ag solution and UV irradiation have a synergistic effect against *S.aureus, C.albicans* and *T. mentagrophytes*. |
| 12 | Erica Dorigatti de Avila et al. (2015) | UV-treated implants showed a significant reduction in bacterial attachment and subsequent biofilm formation compared to cases not treated with UV. |
| 13 | Nagat Areid et al. (2018) | Plaque specimens from the surface of uncoated discs (NC and UVNC) contain approximately twice *S.mutans* compared to $TiO_2$-coated hydrothermal discs (HT and UVHT). Therefore, UV rays cause less biofilm formation. |
| 14 | Dubravko Risovic et al. (2014) | Among UVC (254 nm), UVA (365 nm), violet (406 nm), violet/blue (420 nm), and full-spectrum Xenon light (220-950 nm), eradicating *C. albicans*, UVC radiation had the most effect. |
| 15 | Christiane Silke Heilingloh PhD et al. (2020) | Complete inactivation of SARS-CoV-2 at a concentration of $5\times10^6$ $TCID_{50}$/ml after 9 minutes of combined UVA and UVC exposure is obtained with a dose of 1048 mJ/cm$^2$. |
| 16 | J. D. KRIESEL et al. (1994) | Herpes simplex virus was detected by UV light in 8% of patients with lip lesions and 13% without the disease. |
| 17 | G. J. S. Taylor et al. (1995) | UVC kills bacteria in wounds as well as in the air. |

**Table 3:** Qualitative information obtained from reviewing articles in ultraviolet safety

| Author (year) | Type of study | Sample | Treatment Methods | Criteria |
|---|---|---|---|---|
| Daniel Labrie et al. (2011)[25] | in vitro | 4 types of curing devices:<br>plasma arc, low power LED,<br>high power LED, quartz-tungsten-halogen | 1.blue-light irradiation<br>2. UV irradiation | The lightest radiation in curing devices |
| Anant Agrawa et al. (2013)[26] | in vitro | Mouth and skin tissue | UV Radiation | Oral cancer and skin cancer |

*Trichophyton mentagrophytes* and *Fusobacterium nucleatum* and *Candida* species including *C. albicans, C. glabrota, C. parupsilosis, C. guilliermondii,* and *C. auris.* In addition, the antiviral efficacy of UV irradiation was assessed on airborne viruses such as influenza (H1N1) and human coronaviruses such as alpha HCoV-229E, beta HCoV-OC43, HCoV-NL63, and SARS-CoV-2 as well as HIV and herpes simplex virus.

*Literature on the Safety of UV Radiation*

There were two papers in the safety field (in vitro study) (Tables 3 and 4). One of the articles was related to eye protection methods and the other one related to oral cancer following overexposure to UV radiation.

*Literature on the Applications of UV Radiation*

There were 16 papers in the application field (in vitro studies) (Tables 5 and 6). Three and two

**Table 4:** Results from the review of articles in ultraviolet safety

| | Author (year) | Results |
|---|---|---|
| 1 | Daniel Labrie et al. (2011) | - The most and the least blue light emit when curing the facial side of teeth with Elipar S10 HP LED lamp and SmartLite IQ2 LP LED lamp, respectively.<br>- The most and the least blue light emitswhen curing the palatal side of teeth with Sapphire PAC lamp and Optilux 501 QTH lamp, respectively. |
| 2 | Anant AgrawaL et al. (2013) | UVB radiation can lead to oral and skin cancer while this risk is higher for oral cancer. |

**Table 5:** Qualitative information obtained from the review of articles in ultraviolet application

| Author (year) | Type of study | Sample | Treatment Methods | Criteria |
|---|---|---|---|---|
| Rahul G. Naik et al. (2016)[1] | in vitro | UV disinfection chamber | UV | Number of microorganisms |
| Himanshu Aeran et al. (2015)[3] | in vitro | Dental impression (Alginate and addition silicone, polyether) | 1. UV<br>2. glutaraldehyde 2% | Number of microorganisms |
| David M. Ozog et al. (2020)[27] | in vitro | N95 masks | UVC Radiation | Destroying: SARS-Co-V2 |
| Lei Liao et al. (2020)[28] | in vitro | N95 masks | 1. UVC Radiation<br>2. Heat | Mask efficacy |
| George Byrns et al. (2017)[29] | in vitro | Bacteria on the surfaces | UVC | Destroying microorganisms |
| G. Vinaya Kumar et al. (2015)[30] | in vitro | Elastomeric impression materials | UV | Destroying microorganisms |
| Wei Zhang et al. (2017)[31] | in vitro | Silicon impressions | 1. UV rays<br>2. Glutaraldehyde 2%<br>3. Glutaraldehyde + UV | Destroying HBV, HIV |
| A. Z. Yildirim-Bicer et al. (2014)[32] | in vitro | Acrylic resin | 1.Sodium hypochlorite 1%<br>2. 50% and 100% white vinegar<br>3. Microwave<br>4. UV<br>5. Mouthwash containing propolis (MCP)<br>6. Corega tabs | 1. Destroying microorganisms<br>2.Surface roughness of resin |
| Makarem M. Abdulkareem (2020)[33] | in vitro | Removable prostheses | UV | Bacteria strain |
| Poonam Tomar et al. (2015)[34] | in vitro | Toothbrush germs | 1. UV<br>2. Chlorhexidine 0.2%<br>3. Normal saline | Toothbrush bacteria and fungi |
| Gujjari S. K. et al. (2011)[35] | in vitro | Toothbrush germs | 1. UV<br>2. Microwave | Toothbrush bacteria and fungi |
| KIM BÉLANGER-GIGUÈRE et al. (2011)[36] | in vitro | *S.mutans* In toothbrushes | 1. Listerine mouthwash<br>2. Crest mouthwash<br>3. Microwave<br>4. Dishwasher<br>5. Dry air<br>6. UV | Destroying *S.mutans* |
| Ilkay Peker et al. (2014)[37] | in vitro | Toothbrush microbes | 1. Sodium hypochlorite 1%<br>2. 50% and 100% white vinegar<br>3. Microwave<br>4. UV<br>5. Mouthwash containing propolis (MCP) | Destroying microorganisms |
| Ah-Reum Shin and Seoul-Hee Nam (2018)[38] | in vitro | Toothbrush germs | 1. Chlorhexidine 0.2%<br>2. Povidone-iodine 7.5%<br>3. Sodium Bicarbonate<br>4. UV radiation<br>5. Sterile distilled water | Toothbrush bacteria and fungi |
| Berger, Julius R et al. (2008([39] | in vitro | Toothbrush microbes | 1.VIOlight device<br>2. HIGH DENT device | Destroying microorganisms |
| Zvi Metzger et al. (2007)[40] | in vitro | Tooth root canal | 1. Sodium hypochlorite<br>2. UV<br>3. NaOCl+UV | Destroying microorganisms |

**Table 6:** Results of the review of articles in the application of ultraviolet rays

| | Author (year) | Results |
|---|---|---|
| 1 | Rahul G. Naik et al. (2016) | Placing contaminated instruments in the UV chamber for 60 or 45 minutes, the maximum reduction in CFU is 99.62% or 99.56%, respectively |
| 2 | Himanshu Aeran et al. (2015) | -10 minutes of UV irradiation disinfects the alginate and silicone impressions<br>- 3 minutes of radiation disinfects the polyether impression<br>-2% glutaraldehyde solution for 10 minutes disinfects the impressions |
| 3 | David M. Ozog et al. (2020) | UVC radiation (1.5 J/cm$^2$) is suitable for disinfection of N95 masks infected with the SARS-CoV-2 virus to reuse |
| 4 | Lei Liao et al.(2020) | -UVC (254 nm) with a power of 8W and energy of 3.6 J/cm$^2$ disinfects N95 masks<br>-Disinfection with UVC up to 10 times does not affect the filtration efficiency, but disinfection up to 20 times reduces the efficiency |
| 5 | George Byrns et al. (2017) | The highest effect of UVC on *S.epidermidis* and *B. subtilis* found on contaminated surfaces is at 40-65% RH and 21-24°C temperature. UVC is irradiated from 12.7cm directly to the contaminated surface. |
| 6 | G. Vinaya Kumar et al. (2015) | UV irradiation for 18 minutes has the most effect on reducing colonies in elastomeric impressions |
| 7 | Wei Zhang et al. (2017) | A combination of UV irradiation and immersion in 2% glutaraldehyde effectively disinfects HBV and HIV contaminated silicone impression. |
| 8 | A. Z. Yildirim-Bicer et al. (2014) | UV irradiation significantly reduced *Candida* of acrylic resins; however, 100% white vinegar is the most effective method |
| 9 | Makarem M. Abdulkareem (2020) | 34 bacterial strains (12 gram-negative and 22 gram-positive) were identified in removable prostheses. Two gram-negative and 6 gram-positive strains were destroyed by the first (5 minutes) UV irradiation. The second irradiation killed some other strains and all bacterial strains by the third (15 minutes). |
| 10 | Poonam Tomar et al. (2015) | Using UV radiation for disinfection of toothbrushes was more effective than immersion in chlorhexidine 0.2% |
| 11 | Gujjari S. K. et al. (2011) | Using microwave for disinfection of toothbrushes was more effective than using UV |
| 12 | KIM Bélanger-Giguère et al. (2011) | In terms of the antimicrobial effects on the toothbrush, the efficacy of the methods was as follows: Crest Pro-Health mouthwash > dishwasher > microwave > Listerine mouthwash = dry air > UV light |
| 13 | Ilkay Peker et al. (2014) | UV radiation significantly reduces the number of bacteria on the toothbrushes and has the most significant effect on *S.mutans* compared to microwave, 100% white vinegar and NaOCl |
| 14 | Ah-Reum Shin and Seoul-Hee Nam (2018) | In terms of the antimicrobial effects on the toothbrush the efficacy of methods was as follows: chlorhexidine 0.2% > povidone iodine 7.5% > UV radiation > sodium bicarbonate > distilled water |
| 15 | Berger, Julius R et al. (2008( | HIGH DENT is 50% more effective than VIOlight in reducing bacteria on the toothbrush. |
| 16 | Zvi Metzger et al. (2007) | The combined use of sodium hypochlorite followed by UV radiation reduced bacteria in the root canal by 96%. This condition was also maintained after 14 days. |

articles introduced the application of UV radiation for the disinfection of dental impressions and N95 masks, respectively. Six articles applied UV for the disinfection of toothbrushes. Furthermore, 1 article applied UV on removable prostheses, 1 applied UV on acrylic resins, and 1 article used UV irradiation for contaminated surfaces. Finally, one article used UV for disinfection of the root canal in combination with NaOCl.

## Discussion

*Efficacy*

UV radiation is widely used in dentistry to disinfect the air , while it also works against viruses, bacteria, and fungi. However, radiation time, intensity, moisture content, and direct or indirect radiation to microorganisms affect UV efficiency.[3]

A study that investigated the effect of moisture on the antiviral properties of UV against virus-containing aerosol has shown that the susceptibility of viruses in 55% moisture is higher than in 85% moisture since the absorption of water on the surface of the virus creates a protective layer against UV rays.[10]

The type of nucleic acid is also one factor influencing UV's efficacy against viruses. The dose of UV radiation to inactivate viruses with double-stranded nucleic acid (dsRNA and (dsDNA) is twice the dose needed for viruses with single-stranded nucleic acid (ssRNA and ssDNA).[10]

Several studies evaluated the intensity and duration of UV radiation as some of the most important factors affecting its antibacterial properties. For example, the duration of UVA irradiation for inactivating the microorganisms is different for *Streptococcus mutans*, which plays a crucial role in the formation of dental plaques and tooth caries, and *A.actinomycetemcomitans*, which is frequently found in peri-implantitis.[11]

UVB has bactericidal properties; however, its intensity is less than UVC radiation. For example, 10 and 60 seconds of UVB irradiation reduces the viability of *Streptococcus sanguinis* by 50% and 58%, respectively, and 10-120 seconds of UVB radiation will reduce *S. mutans* viability by 69-74%. Furthermore, it has been reported that UVC radiation for 10 seconds

destroys more than 97% of oral bacteria. UV-LED radiation for 60 seconds produces reactive oxygen species (ROS) such as nitric oxide and hydrogen peroxide from oral epithelial cells, increasing the antibacterial properties. Nitric oxide is effective on *Pseudomonas gingivalis,* while *S. mutans* is sensitive to hydrogen peroxide.[8]

A study on the toxicity of ultraviolet radiation on oral epithelial cells showed that up to 60 seconds of UVB radiation, unlike UVC, has no cytotoxic effects, which means that irradiation of UV-LED 310 nm up to 60 s does not harm oral epithelial cells.[8]

UV light with an intensity of 260 µw/cm$^2$ in 6 minutes and 8000 µw/cm$^2$ in 2 minutes eradicates the Candida albicans biofilm.[12] A study on the eradication of *C. albicans* has shown that among the UVC (254 nm), UVA (365 nm), violet (406 nm), violet/blue (420 nm), and full Xenon light spectrum (220-950 nm), UVC radiation has the most significant effect. Moreover, it has been reported that UVC irradiation for 300 seconds with an energy of 210 mJ/cm$^2$ leads to a 99.9% reduction in the viability of *C. albicans* cultured on poly-methylmethacrylate samples, which is equal to exposure to 3.8% sodium perborate for 5 minutes.[13] Furthermore, another study showed that UV rays with an energy of 103-192 mJ/cm$^2$ are effective for inactivating *Candida auris* while less energy is required for inactivating *C. albicans* (78-80 mJ/cm$^2$).[14]

Far-UVC lights have a narrow range of wavelengths from 200 nm to 222 nm, which is destructive to bacteria but non-destructive to human tissue cells. A study showed that Far-UVC (207-222nm) could eliminate airborne viruses such as influenza (H1N1) and human coronaviruses such as alpha HCoV-229E (1.7 mJ/cm$^2$ UVC 222nm), beta HCoV-OC43 (1.2 mJ/cm$^2$ UVC 222nm), and SARS-CoV-2.[15] According to the studies on beta HCoV-OC43, consecutive far-UVC irradiation (~3 mJ/cm$^2$/hour) for 8, 11, 16, and 25 minutes in a public environment disables 90%, 95 %, 99%, and more than 99.9% of viruses, respectively.

HCoV-OC43 virus from the SAR-CoV-2 family is sensitive to UV radiation with wavelengths of 267 and 279 nm (6 and 7 mJ/cm$^2$, respectively), followed by 286 and 297 nm (13 and 32 mJ/cm$^2$, respectively). Moreover, wavelengths close to 260 nm have a better effect on HCoV-OC43>T7>Enterovirus, Vesivirus>SARS-CoV-2>Qβ, Influenza>MS2> Adenovirus than the wavelength of 280 nm.[16]

The cell-free HIVshould be exposed to UV light for 10 minutes in a UV chamber to be inactivated. However, the inactivation of cell-associated HIV requires more than 30 minutes of exposure.[17]

UVA is also used in combination with other disinfectants. The combined treatment of UVA with silver ions has a s more significant bactericidal effect (on the titanium surface) than UVA or silver ion radiation alone. The antibacterial effect of combination therapy is related to hydroxyl radicals produced from the bacterial cell wall. Silver ions attach to the bacterial cell wall and release hydroxyl radicals under UV-A light. Therefore, the antibacterial function is improved by increasing silver concentration.[11]

Furthermore, applying a combination of silver and UV radiation on electrical appliances using a solution (one ppm) of AgNO3 indicated that the number of *Staphylococcus aureus* bacteria under UV radiation was 1/3 the number of *S. aureus* without UV. Moreover, the number of *C. albicans* under UV was 1/10 the number of *C. albicans* without UV, and the number of *Trichophyton mentagrophytes* under UV was 1/8 the number of *T. mentagrophytes* without UV.[18]

UVA radiation is also used to reduce the microbial load of implants. UV radiation could change the surface of the titanium implant from a hydrophobic state with a contact angle of more than 80° to a super hydrophilic state with a contact angle of less than 5°. This property is maintained for more than 24 hours and even in a liquid environment. UV irradiation for 12 minutes reduces the adherence of bacteria to titanium surfaces and the formation of bacterial biofilms but does not affect the shape of the biofilm, the type of bacteria, and their viability.[19]

UV irradiated titanium disks possess antibacterial activity and are less susceptible to *S. mutans* biofilm formation.[20]

Since $TiO_2$ has antiviral properties against RNA viruses and air and blood pathogens, UV irradiation for more than 5 minutes on $TiO_2$-coated surfaces infected with the HCoV-NL63 virus from the SAR-CoV-2 family leads to the elimination of all viruses.[2]

*Safety*

The retina absorbs light with a wavelength of nearly 400 nm and a high level of energy, resulting in an acute and photoallergic phototoxic reaction, such as in people who stare directly at the sun and arc lamps.[41] The photoallergic reaction occurs after 24-48 h, and the phototoxic reaction occurs at the first exposure (as opposed to the photoallergic reaction) within minutes to several days at higher doses.[42]

Low-wavelength UV radiation is absorbed by the cornea and ocular lens and does not reach the retina, except for children and those whose lens has been removed in cataract surgery and a new lens has not yet been inserted. “Snow blindness” is a transient corneal injury that occurs following exposure to 180-400 nm UV and usually resolves after 48 hours.[42]

The vulnerability of eyes to UV radiation increases after middle age due to the increaseed endogenous UV absorbers and decreased antioxidants. In addition, eye sensitivity to light can be stimulated by medication, dietary supplements, or diagnostic dyes that bind to

ocular tissue and act as UV absorbers, such as malaria and OTC antidepressants.[42]

It should be considered that synthetic ophthalmic lenses do not have adequate protection despite the manufacturer's claim to have a UV filter, and this feature wanes over time.[42]

UVB radiation can lead to oral and skin cancer. Although the annual exposure dose of oral cells to UV is lower than that of skin cells, since oral cells cannot repair DNA damaged by UV radiation, the number of oral apoptotic cells is higher within 24-48 hours after irradiation. Consequently, with the same dose of UV radiation, the risk of oral cancer is higher than skin cancer.[26] On the other hand, the body's mucous membranes, like in the lips, get damaged by the heat produced by the tip of the radiant device, such as light cure devices. This heat cannot be prevented unless the tip of the device is put exclusively on the restoration.

Regarding the destructive effects of UV devices, pulp tissue health also is noteworthy. If temperature increases over 42.5 degrees, it can lead to irreversible effects on the pulp tissue. Therefore, intermittent, non-continuous radiation is recommended.[41]

Newer LED lamps have the same or even higher radiation intensity than halogen lamps, although UVA halogen lamps are widely used in dental offices currently. UV radiation of halogen lamps is not higher than the allowance and is safe for the eyes and skin.[42]

The highest risk of eye damage is caused by blue light at 440 nm (close to the peak wavelength of LED lamps) and by UV radiation at 270 nm.[25] The application of LED lamps is safer for humans. Blue light emits reactive oxygen species (ROS) and causes oxidative stress in the oral tissue. However, antioxidants inhibit such oxidative stress . So far, there have been no reports of clinical damage caused by ROS-induced phototoxicity associated with blue light radiation, but some disorders are due to ROS accumulation.[41]

10-30% of the radiation from the curing devices is reflected toward the the operator's eyes. Using a dark and opaque rubber dam reduces this reflection. The side effects of this reflection on soft tissue depend on the radiation's wavelength, time, and intensity.[42] Orange (predominantly) and bronze filters in glasses can block the blue light, and also the use of magnification loops increases the amount of radiation received by the eye pupil. Therefore, it is necessary to apply appropriate filters on the loops.[41] It has been reported that exposure to blue light with a power of 200 mW/cm$^2$ does not cause damage to human tissue. Notwithstanding, during light curing in dentistry, the power of radiation is above 600 mW/cm$^2$.[41]

An investigation of four types of cure devices (plasma arc, low power LED, high power LED, quartz-tungsten-halogen), has shown that the Elipar S10 HP LED lamp emits the most blue-light irradiation when curing the facial side of teeth, while the SmartLite IQ2 LP LED lamp has the lowest radiation. Moreover, the Sapphire PAC lamp emits the most blue light when curing the palatal side of teeth, while the Optilux 501 QTH lamp emits the least. The maximum radiation occurs when the curing device is used from the palatal side, not the facial side. The ACGIH (American Conference of Government Industrial Hygienists) states that the maximum exposure time for blue light is when the detector is 30-50 cm far from the light source.[25]

The maximum allowable UV exposure time exceeds 8 hours per day, and the minimum daily exposure time for the PAC lamp is 5.96 s when curing the palatal side of the teeth. Therefore, with 1 second of exposure to PAC lamp radiation without goggles, the risk of eye damage is as much as curing with goggles seven times a day. An operator who uses eye protection properly, can look at the PAC from a distance of 30 cm for 10 minutes a day, which equals to120 times of 5-second cycles of curing with PAC.[25]

*Applications*

As mentioned above, UV rays are used in dentistry to disinfect dental offices, materials and equipment, and in medicine to disinfect surfaces and air of hospital rooms and treat diseases such as vitamin D deficiency, psoriasis, and sarcoidosis.

One of the recent applications of UV rays is in the disinfection of N95 masks. UVC radiation with a power of 1.5 J/cm$^2$ was suitable for disinfecting N95 masks infected with the SARS-CoV-2 virus.[27]

Using an N95 mask at 85°C and 30% relative humidity 50 times would not affect the filtration efficiency. UVC (254 nm) with 8W power and energy of ~3.6 J/cm$^2$ is the second choice for disinfecting the N95 masks. The filtration efficiency is not affected following disinfection with UVC up to 10 times, but using UVC 20 times will reduce this efficiency slightly.[28]

One of the broad applications of UV rays is disinfecting equipment and surfaces. Placing the contaminated instrument in a UV chamber for 60 minutes causes a maximum reduction in CFU of 99.62%. A 99.56% reduction in CFU was also observed within 45 minutes.[1] The highest impact of UVC on *Staphylococcus epidermidis* and *Bacillus subtilis* bacteria, which are frequently found on contaminated surfaces, is at 40-65% RH and 21-24 °C temperature. Therefore, UVC should be irradiated from a distance of 12.7 cm directly to the contaminated surface.[29]

The application of UV radiation in the disinfection of impression materials is also common. Alginate is more susceptible to infection compared to the augmented silicon and the polyether impression materials. Ten minutes of UV irradiation causes

complete disinfection of the alginate and silicon impression material, and 3 minutes of radiation is sufficient to disinfect the polyether impression material thoroughly. Placing the impressions in 2% glutaraldehyde solution for 10 minutes eliminates the microorganisms.[3] In the case of elastomeric impressions, the highest reduction in the number of colonies occurs by exposure to UV radiation for 18 minutes.[30] The risk of transfer of microorganisms from alginate impressions is 3-5 times higher than that of the elastomeric impressions.[3] A combination of UV irradiation and immersion in 2% glutaraldehyde effectively disinfects impressions infected with HBV and HIV.[31]

The antibacterial effect of UV radiation on acrylic resins[32] and removable prostheses[33] has been shown. Some studies also show the application of UV radiation in disinfecting contaminated toothbrushes. Although chlorhexidine is considered the gold standard for disinfection of *S. mutans, C. albicans, S. aureus,* and *S. pyogene*s, UV radiation is much more effective in disinfecting toothbrushes compared to chlorhexidine and normal saline. However, the high cost of UV protection equipment necessitates further studies in this field.[34]

Furthermore, exposing toothbrushes to microwave radiation for 5 minutes has shown a more significant reduction in CFU than 12 minutes of UV radiation. However, the results of UV radiation are not statistically different from microwave radiation.[35]

Comparing different disinfectants, placing the toothbrush in the Crest Pro-Health mouthwash for 20 minutes and in the dishwasher eradicates the *S.mutans* bacteria from it. The microwave radiation with the highest power for 5 minutesand Listerine mouthwash for 20 minutes, 4 hours of air dry, and 10 minutes of UV radiation (DenTek Toothbrush Sanitizer) takes the second to fifth place, respectively. Although increasing the dose of UV radiation can kill more microorganisms, the device used in this study turns off automatically after 10 minutes.[36]

UV radiation significantly reduces the number of bacteria and has the most significant effect on *S.mutans*.[37] In addition, the HIGH DENT device is more effective than VIOlight for disinfecting toothbrushes.[39]

## Conclusion

*Efficacy*

1. Viruses are 13-20 times more sensitive to UV rays than bacterial endospores and fungal spores.
2. The bactericidal effect of UV is attributed to hydroxyl radicals released from the bacterial cell wall.
3. The synergistic effect of silver oxide with UV radiation causes the production of hydroxyl radicals, which leads to cell wall damage and the inactivation of mitochondrial enzymes of eukaryotes.
4. While disinfecting the titanium implants with UV radiation, the implant surface becomes hydrophile, a vital factor during wound healing and bone formation.
5. Several factors such as radiation dose, material's surface, and moisture content influence the efficiency of UV rays against various viruses, including the SAR-CoV-2.
6. The effect of UV on HIV depends on the number of proteins around the virus to protect it. Cell-associated HIV in the blood must be irradiated in a UV chamber for more than 1 hour to become completely inactivated .

*Safety*

1. UV radiation can lead to NO's release from intracellular mitochondria (hemoglobin and nitrosothiol) and cause damage to the mitochondrial electron transport chain, and ultimately neurological defects and cell death (eye and skin damage).
2. Far-UVC radiation can kill viruses and bacteria in micrometers, but it cannot penetrate the stratum corneum (the outermost layer of skin with dead cells), the lacrimal layer of the eye, or even the cytoplasm of human cells. As a result, it can be used in low doses in public places to reduce the spread of airborne viruses.
3. With the same dose of UVB radiation, the risk of oral cancer is higher than skin cancer.
4. The best advice to reduce the harmful effects of UV radiation is to follow the blue lamps manufacturer's instructions and use eye protection filters.

*Application*

1. Placing contaminated equipment in a UV chamber for 60 minutes reduces 99.62 % of the microorganisms.
2. The highest effect of UVC on bacteria in contaminated surfaces is at 40-65% humidity and 21-24°C. Therefore, UVC should be irradiated from a distance of 12.7 cm directly to the infected surface.
3. Eight-watt UV light with an energy of 3.6 J/cm$^2$ can be used for the disinfection of N95 masks. The filtration efficiency is not affected by up to 10 times disinfection with UVC.
4. Using UV for root canal therapy is an effective adjunct for the disinfection of contaminated root canals in a short time.
5. UV radiation is used to control respiratory diseases through air disinfection.
6. UV rays can be used to disinfect toothbrushes, impression materials, and removable dentures.
7. UVB radiation can activate vitamin D in the epithelium. Vitamin D also helps osteogenesis by regulating calcium homeostasis.

**Conflicts of interest:** None declared.

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