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Literature Review

Photodynamic Therapy 405 nm Diode Laser as Antibacterial for Cavity and Root Canal Sterilization

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ABSTRACT

Background: *The goals of caries restoration and endodontic treatment are to repair and prevent the infection from getting worse and if possible, heal the damaged tissue. To achieve this goal, it is necessary to control the presence of microbes in the cavity or root canals with chemo mechanics prior to filling or obturation of the root canals. Disinfection methods using disinfectants with effective bactericidal activity are mostly used at subtoxic levels and at concentrations where their toxicity is a significant factor. In addition, the disinfection method is considered unable to achieve thorough cavity cleaning and causes secondary infection. A new method to provide better disinfection without cytotoxic effects has recently been discovered using the photodynamic method of 405 nm diode laser therapy. Research continues and is progressing with the existence of various factors that affect the effectiveness of the 405nm diode laser as an antibacterial.* **Purpose:** *To evaluate the results of research on photodynamic diode laser therapy with a wavelength of 405 nm as a combination antibacterial therapy in cavity and root canal sterilization techniques.* **Review(s):** *Literature study in the form of narrative review using libraries obtained through the PubMed and Google Scholar databases. The optimal bacterial mortality was influenced by the form factor of the target bacteria, the energy dose and duration of laser exposure, and the type of photosensitizer used.* **Conclusion:** *The use of a 405 nm diode laser with an energy power of 50 mW with a distance of 20 mm can degrade biofilms Streptococcus mutans up to 100% using erythrosine photosensitizer, for 75 seconds. And with the same power and distance, it can degrade the biofilm of bacteria Enterococcus fecalis up to 97.51%, using a photosensitizer chlorophyll, for 120 seconds.*

Keywords: *Antibacterial; Photodynamic therapy; 405 nm diode laser; Photosensitizer*

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INTRODUCTION

Streptococcus mutans (*S. mutans*) and *Lactobacillus acidophilus* (*L. Acidophilus*) are the most important bacterial colonies that are responsible for the occurrence of dental caries, and *S. mutans is* considered the main cariogenic organism. *Staphylococcus aureus is* one of the causes of root canal infections and is a persistent facultative anaerobic bacterium. According to Yamin *et al.,* 2014 *Staphylococcus aureus* bacteria were found in 20% of the root canals of necrotic teeth[1]. Secondary infection post endodontic treatment can also lead to endodontic failure[2]. Several studies have shown that *Enterococcus faecalis* is more common in cases of endodontic treatment failure. Among all reported cases of pain and post endodontic therapy infection, it was observed that E. faecalis was the most common, with a high prevalence rate of up to 90%.

Cleaning of the cavity before filling and sterilizing the root canals before obturation in endodontics was carried out by applying disinfectant material. Chlorhexidine is known as the gold standard for antibacterial agents as a disinfectant cavity, and sodium hypochloride as the gold standard for root canal irrigation[3]. Antibacterial chemical agents can help reduce the number of pathogenic bacteria. However, this prevention method cannot cover the entire population so that the tooth cavity is still formed[4]. In addition, most of the disinfection methods that use disinfectants with effective bactericidal activity are used at sub-toxic levels, and at concentrations where toxicity is an important factor[5].

Given the shortcomings of disinfectants for cavity and root canal sterilization, a tool was developed that provides better disinfection without cytotoxic effects using the photodynamic method of laser therapy. Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. There have been many studies examining the effectiveness of lasers as anti-bacterial tools in caries and root canals. Photodynamic Therapy (PDT) disinfectant method which was studied is known as Photo Activated Disinfection (PAD). Diode lasers are currently being researched for their use as PDT in their function as an

antibacterial, one of the most common is violet blue light which is the diode laser. The antimicrobial effect of violet-blue light with peak activation power is at a wavelength of 405 nm. This absorption of light by the laser is carried out using endogenous porphyrin resulting in the production of reactive oxygen species, including H2O2 and singlet oxygen, which cause oxidative damage and cell death.

This review article is to summarize the recent developments regarding the photodynamic therapy (PDT) of 405nm wavelength diode laser in dentistry especially for cavity disinfection of caries and root canals in endodontic treatment.

REVIEW(S)

Photodynamic Therapy (PDT) is a form of phototherapy that involves light, photosensitizing chemicals, and molecular oxygen, resulting in cell death (phototoxicity). PDT has the proven ability to kill microbial cells, including bacteria, fungi, and viruses[6]. Photo-activated disinfection (PAD) is a disinfection method that uses a photosensitization application and then irradiates it with a laser[7]. The antimicrobial effect of the laser *violet-blue* has been investigated using a wavelength in the 400- 420 nm region, with peak activation power shown at 405 nm[8].

Photodynamic therapy is based on the use of a combination of a photosensitizer and a suitable visible light wavelength to form free radicals or superoxide ions from the transfer of hydrogen or electrons producing reactive oxygen species (ROS). ROS will react with the surrounding molecules and exert a bactericidal effect on the target microorganisms[4]. Photosensitizer has the ability to absorb specific light. The photosensitizer's ability depends on a specific wavelength of light emitted to cause bacterial cell death.

Photosensitization oxidation is the basis for photodynamic reactions. PDT involves three main components, namely light, *photosensitizer*, and oxygen. The first step in this reaction is the absorption of light by the sensitizer to produce an excited sensitizer state. In the presence of oxygen, two reactions (reacting with the substrate or solvent (Type I) or with oxygen (Type II)) of an excited sensitizer state can occur. The excited sensitizer then turns into a triplet sensitizer via the mechanism intersystem crossing (ISC). Triplet state photosensitizer can react via Type-I and Type-II processes. Type I reactions involve an electron transfer reaction between the excited state of the *photosensitizer* and the molecules of the cell's organic substrate, producing free radicals[9]. Singlet oxygen can interact with many biological substrates inducing oxidative damage to cell membranes and cell walls of bacteria, viruses and fungi[10].

Photodynamic therapy as an anti-bacterial therapy is based on exogenous compounds photosensitizer that will bind to pathogenic bacteria. Anionic surface in bacteria acts as an electro-attractive to the photosensitizer cationic, thereby causing photosensitizer more efficiently bound and entry into bacteria[11]. Photosensitizer which has tied up with the bacteria will cause electrostatic interactions between the photosensitizer and the bacterial cell wall that ion release of Ca^{2+} and Mg^{2+} out of the cell so that the permeability of the wall bacterial cell increased[5]. The increase in permeability of the bacterial wall will cause the photosensitizer to diffuse into the plasma membrane and the cytoplasm of the bacteria.

Apart from the use of a photosensitizer, another determining factor is the radiation energy dose. The right dose of energy activates chemical reactions that produce various ROS resulting in death in bacteria. The laser irradiation energy dose per total irradiated area (power density, units J/cm^2) is the amount of radiation energy (power multiplied by longer exposure time) divided by the total area of irradiation. This determines the duration of the laser irradiation time adjusted to the energy dose and quantum yield of the laser used[12].

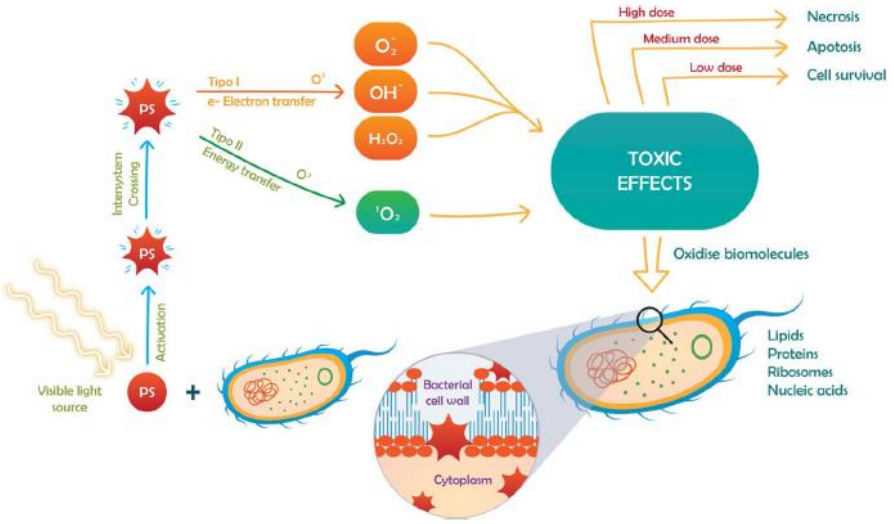

Figure 1. Schematic of the antibacterial mechanism of photodynamic therapy[9].

DISCUSSION

Photodynamic antibacterial therapy using a diode laser with a wavelength of 405 nm is a photodynamic therapy currently being developed for combined antibacterial therapy in cavity and root canal sterilization. There are several factors that must be considered for the 405 nm diode laser to be the antibacterial therapy with the most effective potential. *Streptococcus mutans* (*S. mutans*), *Lactobacillus acidophilus* (*L. Acidophilus*), *Enterococcus faecalis (E. Faecalis), and Staphylococcus aureus (S. aureus)* discussed in this literature are some of the bacteria that most play a role in caries, and the microorganisms that resistant and survivable in root canals after biomechanical preparation leading to failure of endodontic treatment.

Three basic components are needed in a photodynamic reaction, namely a photosensitizer in the form of a photosensitive molecule that can localize itself in the cell or in the target tissue, a light source with a certain wavelength needed to activate the photosensitizer, and molecular oxygen which is essential for the formation of reactive oxygen species (ROS). The energy dose is directly proportional to the exposure time used, the more the exposure time is given, the higher the energy dose generated from the 405 nm diode laser. The energy dose of 20 J / cm^2 can kill *Streptococcus mutans* bacteria as much as 61.9%[13]. In 2016, with the higher dose Astuti use energy dose of 25,34 J / $cm^2$with a time of 75 seconds, was able to kill the bacteria *Streptococcus mutans* as much as 74.03% using *photosensitizer* chlorophyll[14]. An increase in the number of bacterial deaths resulted by increasing the energy dose to 30 J / $cm^2$and the exposure time increased to 150 seconds resulted in a higher percentage of bacterial death, namely 99.26% using *photosensitizer* curcumin[15]. For bacteria *Staphylococcus aureus,* the energy dose generated from 120 seconds of exposure time, amounting to 22.56 J / cm2 can kill *Staphylococcus aureus* bacteria with a percentage of 55.22%[16]. With a lower energy dose of 16.19 J / cm2 and with the same exposure time it can kill as much as 91.49%. From these results it can be said that the ideal energy dose is not always the highest energy dose, because optimal bacterial death does not always use the highest energy dose.

The light source from the laser has an energy intensity related to the power per unit area of laser exposure. The intensity of the diode laser exposure indicates the number of photons emitted, and the laser energy dose represents the intensity that the laser produces in a certain time. More power with a small surface area results in a greater intensity. The greater energy density / laser diode dose, the more high-energy photons can absorb by photosensitizer molecule. The greater the photon intensity and the longer the exposure time, the more photosensitizer is activated to produce various ROS which affect the number of bacterial deaths. The photosensitizer used in the 405 nm diode laser therapy will be optimal only when the photosensitizer is used in accordance with the 405 nm wavelength spectrum. Bactericidal effect of laser diodes views of the susceptibility of bacteria to laser exposure to certain wavelengths when combined with *photosensitizer* the appropriate[15].

The susceptibility of bacteria to PDT differs according to PS type even for the same bacterial strain. Bacteria were *Streptococcus mutans* found to be susceptible to the *photosensitizer* curcumin and photo porphyrin IX, and not susceptible to riboflavin and resazurin[17]. The percentage of bacteria death *S. mutans* can reach 99.26% by using the *photosensitizer* curcumin[15]. Meanwhile, by using chlorophyll, bacterial mortality can be achieved up to 74% [14]. The bacterial mortality *S. mutans* most optimal is achieved by using erythrosine as a photosensitizer which can produce the bacteria death by *S. mutans* most up to 100%, so it can be said that erythrosine is photosensitizer the most effective for bacteria *S. mutans* by using a 50mW laser power for 75 seconds[18]. The use of photosensitizer chlorophyllin PDT can degrade the biofilm which *Enterococcus faecalis* can achieve bacterial death up to 97.51%[19], degradation of biofilm *Staphylococcus aureus* as much as 98%[20] and in biofilm *Lactobacillus acidophilus* which can kill 99.33%[21].

The resistance of bacteria in biofilms is known to be more resistant to the presence of antimicrobial therapy than planktonic microorganisms. The interaction of molecules photosensitizer and Extracellular Polymeric Substance matrix (EPS) even without a light source can affect the cohesion and stability of the EPS matrix, causing polysaccharide damage to the EPS matrix. However, after applying a light source, the polysaccharide level was considerably reduced by 80%[22]. Research conducted by Astuti *et al.,* 2016, stated that a 405 nm diode laser against planktonic bacteria can reduce the number of planktonic bacteria *S. mutans* by 74% in just 75 seconds with a *photosensitizer* chlorophyll[14]. As for the percentage of EPS degradation, the biofilm bacteria *S. mutans* reached 98% with a longer exposure time of 120 seconds[23]. With the same exposure time of 120 seconds, it showed degradation of the EPS biofilm *Staphylococcus aureus* a significant 98%[20]. So, it can be said, it is possible that if planktonic bacteria are *S. mutans* given the same laser exposure as biofilms for 120 seconds it can produce more optimal mortality than biofilm death *S. mutans,* because in just 75 seconds planktonic bacteria can kill as much as 74%. Likewise, the death of the planktonic bacteria *Enterococcus faecalis* which was given exposure to a 405nm diode laser with chlorophyll was able to kill bacteria up to 81.29%[24]. *Enterococcus faecalis* bacteria which form a biofilm when given chlorophyll and irradiated with a 405nm diode laser can degrade EPS biofilms up to 97.51%[19]. Degradation of the bacterial biofilms obtained greater results probably due to the different duration of laser irradiation, 120 seconds on biofilms and 60 seconds for planktonic bacteria.

Photodynamic therapy using a *photosensitizer* can reduce the number of bacteria in the form of biofilms less than planktonic bacteria, this is possible because of the heterogeneity of biofilms, limited penetration of microbial agents penetrating material *extracellular matrix,* decreased cell growth in biofilms, and differences inexpression

genetic on biofilms[25], and the biofilm has the strength of the supporting network and resistance to antimicrobial substances[26].

Photosensitizer cationic is more effective against bacteria than *the photosensitizer* anionic, due to adhesions and uptake *photosensitizer* anionic by the cells of the bacteria is lower than photosensitizer cationic[27]. Cationic molecules carry a positive charge on their functional groups, so they are easily bound and taken up by bacteria that have a negative charge on the surface[28]. In addition to the type of *photosensitizer,* photodynamic antibacterial therapy is more effective in killing gram-positive bacteria because the outer wall layer of the bacteria contains peptidoglycan and lipoteichoic acid, making it more porous and will make it easier for the *photosensitizer* to penetrate the plasma membrane[29].

The peak absorption of the erythrosine photosensitizer is at a wavelength of 532 nm[30]. Research that has been done says that a 405 nm diode laser with erythrosine photosensitizer can kill bacteria *Streptococcus mutans* with a percentage of 100%[18]. The use of erythrocyte photosensitizer was also carried out by Merigo *et al.,* 2019 against bacteria *Streptococcus mutans* which can also result in total death of 100% bacteria[15]. The mortality results obtained, in conditions without erythrosine irradiation, were able to show a bacterial inhibiting effect up to 82% compared to negative controls.

The absorption spectrum of chlorophyll as a *photosensitizer* at a wavelength of 300 - 900 nm was measured from a UV-Vis spectrophotometer with the percent absorption of chlorophyll at a wavelength of 405 nm (laser diode) of 99.51%[14]. Chlorophyll as a *photosensitizer* with 405 nm diode laser irradiation showed the most optimal results in the use of a 405 nm laser on biofilm *Lactobacillus acidophilus* which killed 99.33%[21]. Meanwhile, the percentage of death of the bacteria *Streptococcus mutans* was 98%[23], and against the bacteria *Enterococcus faecalis* was 97.51%[19].

The best absorption of *curcumin* is in the region of 420–450 nm. With 405 nm LED irradiation, *curcumin* showed antibacterial activity even at low concentrations[31]. The susceptibility of bacteria was *Streptococcus mutans* shown by administering a 405 nm laser with *photosensitizer* curcumin and protoporphyrin IX[17]. Diode laser with a wavelength of 405 nm applied with a *photosensitizer* curcumin can kill the most optimal bacteria, namely *Streptococcus mutans* up to 99.26%[15].

In its ability to kill bacteria, 405 nm diode laser photodynamic therapy influences the surrounding tissue. Research conducted by Ramakrishnan *et al*., 2014 showed that exposure of bacterial cells to laser light 405 nm up to a dose of 36 J cm^2 did not cause detectable damage to cell viability, function, proliferation rate, and morphology in mammalian cells[32], and remained can cause a significant bactericidal effect. Exposure period of more than 2 hours at a radiation level 5 mW / cm2 (> 36 J / cm^2) is toxic to cells that cause cell function and cell death, in other words the higher doses, there is a negative impact on cell viability, function, and the rate of cell proliferation. In addition, the viability test on the 405 nm diode laser was carried out by Nizar *et al.,* 2020 using BHK-21 cell culture from fibroblasts, it was found that more than 80% of the viability of fibroblast cells after exposure to the 405 nm diode laser at a distance of 7 mm, 10 mm , 13mm, and 16mm. Whereas in the treatment with a distance of 4mm, the results showed that there was an increase in the number of fibroblast cells, although not too significant, namely by 4.09%[33].

In addition to time variations, the use of diode lasers with time variations used to see cell viability showed that the irradiation time of 30, 60, 120, and 240 seconds had no effect on the viability of BHK-21 fibroblast cells, this happened because the cell chromophore did not absorb enough energy of photons to stimulate the biological activity of the cell. In the 480 second treatment, the viability of BHK-21 fibroblast cells increased by 12.1%. With a time of 480 seconds, the energy absorbed by the cell is sufficient to stimulate the biological activity of the cell to allow a 405 nm diode laser bio stimulation response, resulting in an increase in BHK-21 fibroblast cells[34].

CONCLUSION

Bacterial biofilms of *Streptococcus mutans* and *Enterococcus faecalis* are the most virulent bacterial colonies associated with caries and failure of endodontic treatment. The use of a 405 nm diode laser with an energy power of 50 mW with a distance of 20 mm can degrade biofilms *Streptococcus mutans* up to 100% using erythrosine photosensitizer, for 75 seconds. And with the same power and distance, it can degrade the biofilm of bacteria *Enterococcus faecalis* up to 97.51%, using a *photosensitizer* chlorophyll, for 120 seconds.

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REFERENCES

1. Yamin IF, Natsir N. Bakteri Dominan di dalam Saluran Akar Gigi Nekrosis. Dentofasial. 2014; 13(2): 113-116.
2. Pereira RS, Rodrigues VVA, Furtado WT, Gueiros S, Pereira GS, Avila-Campos MJ. Microbial analysis of root canal and periradicular lesion associated to teeth with endodontic failure, *Anaerobe.* 2017; 1-24.
3. Iqbal A. Antimicrobial Irrigants in the Endodontic Therapy. International Journal of Health Sciences. 2012; 6(2): 153-8.
4. Paschoal M, Tonon C, Spolidório D, Bagnato V, Giusti J, Santos-Pinto L. Photodynamic potential of curcumin and blue LED against Streptococcus mutans in a planktonic

culture. *Photodiagnosis and Photodynamic Therapy.* 2013; 10(3):313-319.
5. Diogo. P, Gonçalves T, Palma P, Santos J. Photodynamic Antimicrobial Chemotherapy for Root Canal System Asepsis: A Narrative Literature Review. *International Journal of Dentistry.* 2015; 1-26.
6. Saini R, Lee N, Liu K, Poh C. *Prospects in the Application of Photodynamic Therapy in Oral Cancer and Premalignant Lesions. Cancers.* 2016; 8(9): 83.
7. Johar K. Fundamentals of Laser Dentistry. New Delhi. Jaypee Brothers Medical Publishers (P) Ltd. 2011. Pp: 134-7.
8. Gillespie JB, Michelle M, Given MJ, Wilson MP, Judd MD, Timoshkin IV, MacGregor SJ. Efficacy of Pulsed 405-nm Light-Emitting Diodes for Antimicrobial Photodynamic Inactivation: Effects of Intensity, Frequency, and Duty Cycle. *Photomedicine and Laser Surgery.* 2017; 35(3): 150-5
9. Reis A. C. M., W. F. M. Regis, L. K. A. Rodrigues. Scientific Evidence in antimicrobial photodynamic therapy: An alternative approach for reducing cariogenic bacteria. Photodiagnosis and photodynamic therapy. 2019; 29: 179-189.
10. Rajesh S, E. Koshi, K. Philip, A. Mohan. Antimicrobial *Photodynamic Therapy*: An Overview. *Journal of Indian Society of Periodontology*. 2011; 15(4): 323-327.
11. Liu, Y., R. Qin, S. A. J. Zaat, E. Breukink, and M. Heger. . Antibacterial photodynamic therapy: overview of a promising approach to fight antibiotic-resistant bacterial infections. *Journal of Clinical and Translational Research*, 2015; 1(3): 140-167.
12. Astuti S. D. An in-vitro antimicrobial effect of 405 nm laser diode combined with chlorophylls of Alfalfa (Medicago sativa L.) on Enterococcus faecalis. *Dent. J.* (Majalah Kedokteran Gigi). 2018; 51(1): 47–51.
13. Astuti S. D., S. A. Sunarko, W. Ekasari. Antimicrobial effect of pleomeleangustifolia pheophytin A activation with diode laser to streptococcus mutans. IOP Conf. Series: Journal of Physics. 2017; 853: 1-6.
14. Astuti S. D., A. Zaidan, E. M. Setiawati, Suhariningsih. Chlorophyll mediated photodynamic inactivation of blue laser on Streptococcus mutans. AIP Conference Proceedings. 2016; 1718: 120001-1–8.
15. Merigo E., S. Conti, T. Ciociola, M. Manfredi, P. Vescovi, C. Fornaini. Antimicrobial Photodynamic Therapy Protocols on Streptococcus mutans with Different Combinations of Wavelengths and Photosensitizing Dyes. Bioengineering. 2019; 6(42): 1-10.
16. Astuti S. D., I. W. Widya, D. Arifianto, R. Apsari. Effectiveness Photodynamic Inactivation with Wide Spectrum Range of Diode Laser to *Staphylococcus aureus* bacteria with endogenous Photosensitizer. Journal of Internatonal Dental and Medial Research. 2019; 12(2): 481-486.
17. Kang S. M., H. Jung. Kim B. Susceptibility of Oral Bacteria to Antibacterial Photodinamic Therapy. Journal of Oral Microbiology. 2019; 11: 16441 11.
18. Kunarti S., A. Dita, W. Saraswati. The Duration Effectivity of Diode Laser 405 nm with Erythrosine Photosensitizer in Killing Streptococcus Mutans. *Conservative Dentistry Journal*. 2020; 10(1): 1-4.
19. Santoso M L. Degradasi Extracellular Polymeric Substance Biofilm *Enterococcus faecalis* Akibat Lama Paparan Laser Diode 405nm. Repository Universitas Airlangga. Surabaya. 2018
20. Sudjarwo K E. Degradasi Extracellular Polymeric Substance (EPS) Biofilm Bakteri *Staphylococcus aureus* Akibat Waktu Paparan Laser Diode Panjang Gelombang 405nm dengan Fotosensitizer Klorofil. Repository Universitas Airlangga. Surabaya. 2018.
21. Ruslan M I. Degradasi Extracellular Polymeric Substance (EPS) Biofilm *Lactobacillus acidophilus* Akibat Waktu Paparan Laser Diode 405nm dan Fotosensitiser Klorofil. Repository Universitas Airlangga. Surabaya. 2018.
22. Hu X, Huang Y, Wang Y, Wang X, Hamblin M. R. Antimicrobial Photodynamic Therapy to Control Cinically Relevant Biofilm Infection. Frontiers in Microbiology. 2018; 9(1299): 1-24
23. Tasniadara I. Degradasi Extracellular Polymeric Substance Biofilm Bakteri *Streptococcus mutans* Akibat Paparan Laser Diode 405nm. Repository Universitas Airlangga. Surabaya. 2018.
24. Tjandra A, Kunarti S, Prasetyo EA. Efficacy of Diode Laser 450nm with Chlorophylls as Photosensitizer on Enterococcus Faecalis. *Conservative Dentistry Journal*. 2018; 8(2). Pp : 31-35
25. Freire F.C., A. C. B. Pereira, Pereira, C. Aparecida; B. Junior, Milton, Junqueira, J. Campos, Jorge, A. O. Cardoso. Comparison of the effect of rose bengal- and eosin Y-mediated photodynamic inactivation on planktonic cells and biofilms ofCandida albicans. Lasers in Medical Science. 2014; 29(3), 949–955.
26. Street, Cale N.; Pedigo, Lisa A.; Loebel, Nicolas G. (2010). *Energy Dose Parameters Affect Antimicrobial Photodynamic Therapy–Mediated Eradication of Periopathogenic Biofilm and Planktonic Cultures. Photomedicine and Laser Surgery.* 2010; 28(S1), S-61–S-66.
27. Pereira CA, Costa AC, Carreira CM, Junqueira JC, Jorge AO. Photodynamic inactivation of Streptococcus mutans and Streptococcus sanguinis biofilms in vitro. Lasers Med Sci. 2013; 28(3):859-64.
28. Ghorbani J., R. Dariush, A. Shahin, T. Alireza, B. Abbas. Photosensitizers in antibacterial photodynamic therapy: an overview. *Laser Therapy.* 2018; 27(4): 293-302.
29. Carrera, E T; Dias, H B; Corbi, S C T; Marcantonio, R A C; Bernardi, A C A; Bagnato, V S; Hamblin, M R; Rastelli, A N S. *The application of antimicrobial photodynamic therapy (aPDT) in dentistry: a critical review. Laser Physics,* 2016; 26(12), 123001.
30. Silva, A.F.; Borges, A.; Freitas, C.F.; Hioka, N.; Mikcha, J.M.G.; Simões, M. Antimicrobial Photodynamic Inactivation Mediated by Rose Bengal and Erythrosine Is E_ective in the Control of Food-Related Bacteria in Planktonic and Biofilm States. 2018; 23, 2288.
31. Lee H. J., S. M. Kang, S. H. Jeong, K. H. Chung, B. Kim. Aantibacterial Photodynamic Therapy With Curcumin and Curcuma Xanthorrhiza Extract Against Streptococcus mutans. Photodiagnosis and Photodynamic Therapy. 2017; 1-14.
32. Ramakrishnan P., M. Michelle, M. Scott J, A John G., M. H. Grant. Differential sensitivity of osteoblasts and bacterial pathogens to 405-nm light highlighting potential for decontamination applications in orthopedic surgery, 2014; 19 (10), 105001.
33. Kunarti S., V. Z. Nizar, W. Saraswati. Viability Test of Photodynamic Therapy with Diode Laser Waves Length 405 nm on BHK-21 Fibroblast Cells with Various Irradiation Distances. *Conservatve Dentistry Journal.* 2020; 9(2): 82-86
34. Ismiyatin K, L. H. Rumbiak, W. Saraswati, S. Kunarti, A. Bhardwaj. Pengaruh Variasi Lama Laser Dioda 405nm Terhadap Viabilitas Sel Fibroblas BHK-21. *Conservative Dentistry Journal*. 2019; 9(1). Pp: 13-8