The Effect of Beam Direction on Absorption and Transmission of Ultraviolet to Infra-red Wave-length in Three Different Dentin Thicknesses

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Abstract

Backgrounds

Lasers and optics have extensively been used in dental procedures in recent years, so realizing the optical properties of the tooth represents a milestone in its successful applications. the aim of this study was to compare the absorption and transmission of applied wavelengths in 190-1100 nm range in various dentin thicknesses and the effect of changing the direction of beam emission in dentinal tubules.

Methods

Fifteen dentin specimens with a thickness of 300, 600, and 1000 μm and five specimens from each thickness were prepared by a transverse incision at the upper pulpal roof area of the human molars.

Considering the Corono-apical and Apico-coronal direction, we measured the absorption and transmission of parallel light beams perpendicular to the dentin specimens in various thicknesses and two directions using a UV/ Visible spectrometer.

Results

The ultraviolet wavelength's absorption rate was significantly higher than visible and infrared light irradiation from both directions in three thicknesses (p-value<0.001). Additionally, The radiation beam displacement had no significant differences in the absorption and transmission of ultraviolet, visible, and infrared light in any of the three thicknesses (p-value>0.05).

Conclusion

According to the results, the change in the beam direction during irradiation does not cause a significant difference in light absorption. Furthermore, the results are expected to develop a suitable method for evaluating the trans-dental performance of different optical parameters for diagnostic purposes in the dental tissues.

Background

Understanding the optical characteristics of the dentin is deemed necessary in various areas of odontology. The domain of these effects is important from diagnostic, clinical, and cosmetic aspects as the adaptation of color plays a key role [1–3]. Additionally, the effects of the laser light on mechanisms associated with cavity preparation and treating the surface of dentin [4, 5] as well as the process of disinfection [6], and different dimensions of tissue regeneration are well evident [7, 8].

These effects are well used now and the applications of lasers and LEDs in various treatments of different areas of odontology have gained remarkable attention and proved highly efficient [9–12].

Lasers are utilized in endodontic treatments to create access cavity preparation and to treat the dentin in the canal to remove the smear layer. Moreover, they are widely used and proved effective to disinfect the root canal**s** and dentinal tubules [13, 14]. In addition to the aforementioned areas, in recent years, the application of laser has gained momentum to stimulate the cells in studies on treatment and regeneration [15–17].

Using laser in the range of blue light to infrared light in the root canals lead to various effects in the dentinal tissue, including a photo-thermal disinfection effect [18, 19], developmental stimulation of the healing process for the surrounding tissues in the alveolus [17, 20], and activation of the irrigation solutions in the canal [21]. Therefore, it has been suggested as an important tool for disinfection of the root canals and its dentinal microtubules in Endodontics [21, 22].

The morphology of dentinal tubules and geometrical pattern of their alignments are further important in the distribution and propagation of light [23–25] because in many cosmetic treatments and bleaching processes [26, 27] as well as the treatment of dentin hypersensitivity [28, 29], the pattern of laser's beams is from the outside of the dentin to its inside. When light radiates into the biological tissues, a combination of absorption, transmission, reflection, and scattering occurs and, taking into account the anisotropic nature of these tissues, the optical characteristics and patterns of light distribution in these tissues are fundamentally dependent on patterns of elements and tissue microstructures relevant to the source of light [25, 30, 31]. Dentinal tubules possess a hyper-mineralization in the canal wall which, due to the conical shape of these dentin microstructures, could change the absorption patterns and beam distribution [32, 33].

The estimation of beam absorption in dentin or any other tissue is a function of the frequency and wavelength of that light [34–36]. However, few studies have investigated the patterns of laser's beam absorption in dentin and, particularly the depth of penetration and its effect on amount of absorption and distribution [23, 31, 37].

Considering the gap in the literature, the aim of the present study was to investigate the absorption scale and transmission of beam and, the effect of changing the direction of beam emission in dentinal tubules within the range of ultraviolet and infrared light which is conducted using the spectroscopy absorption method in three thicknesses of 300, 600 and 1000 μm as the dentinal disks.

Materials And Methods

In this experimental laboratory study, the population were the extracted molar teeth because of periodontal problems. According to Table 1, in Masyuki Otsuki et al. study [23] with 90% power, 95% confidence, and 70% drop (as the discs are fragile and the probability of fracture is very high in the experiment), the maximum sample size was obtained as five in each group for more accuracy.

Following the ethics committee's approval at Golestan University of Medical Sciences, 15 healthy molars without cracks, defects, or morphological changes which was periodontically hopeless, were extracted and collected. The teeth were first cleaned and kept for 15 minutes in 2.5% sodium hypochlorite solution for disinfection, rinsed with double distilled water, and kept in 0.5% chloramine-T solution until the study started [38, 39]. Then, for more similarity in the alignment of the dentin tubules, the sample preparation in three thicknesses 600, 300, and 1000 µm had to be prepared perpendicular to the tooth's longitudinal axis in the pulp chamber's upper area. Therefore, five specimens were placed in each group given the sample size.

A water-cooled diamond blade cut each molar tooth on a precision cutting machine (Mecatome, Presi, France) to obtain these thicknesses' cross-sections. To this end, we first placed the teeth in a transparent resin block. Then the block was used to cut under the machine. It was cut in parallel at the desired increment on this block, where usually one usable sample was obtained from each block.

After that, we first used 10 ml EDTA 17% (PULPDENT, Waterson, MA, USA) and then washed with 10 ml NaOCl 5% each for one minute to remove the smear layer and finally washed with 10 ml of distilled water to remove any possible deposits of disinfectants [40].

We had first to fix the specimens between two pieces of the Plexiglas's slide with a gap of 5 mm in width and 2.5 cm in length in the middle of them during irradiation. This gap is situated in front of the light source where the sample is placed in the spectrophotometer's holder. This design is essential to remove interfering factors like the slide thickness to pass a beam of light through the slot slope and direct radiation to the sample.

Taking into account the conical structure of the dentin tubules, to analyze the optic from both directions of radiation on the samples, i.e. both in occlusal to cervical and cervical to occlusal directions (Fig. 1), so preservation and transfer of the sample direction were done very carefully, and its direction was marked on the slide.

Considering the range of inevitable behaviors in the parameters of geometric measurement with changes in the source of beam, absorption determination could be accompanied with justifiable errors. However, the fact that the amount of absorption depends on the wavelength is important and it is recommended in experiments conducted for determining the absorption of biologic tissue using the beam sources with continuous radiation scale [33]. For this reason, the present study used the Cecil; CE 7400 UV/VISIBLE, Cecil instrument limited, England spectrometer device to examine the beam absorption. This spectrometer employs an emission spectrum within the 190 to 1100 nm wavelength (within the UV range: at two wavelengths of 220 and 255; within the invisible light range: at the wavelengths of 445, 515, 632.5, and 660; and within the IR: at the wavelengths of 810, 940, 980, and 1065 nm) as a source of light and is able to measure the transmission and absorption curves with high accuracy and speed for liquid and narrow solid samples within this spectrum of wavelength.

Light perpendicular to the objects is directed in fixed distance and, immediately upon the experimented samples, the transmitted ray is directed to the spectrophotometer of the device (Fig. 2). After measuring the spectrum of absorption for the samples within the range of the aforementioned wavelength, the amount of beam absorption in specified wavelengths can be extracted from the absorption spectrums and determine the changes of ray transmission depending on the thickness of the samples. Moreover, there is a possibility to study the effect of changing the direction of beam in the thickness of dentin discs on the amount of beam absorption and this could be considered depending on the amount of absorption by the device and its standard algorithm.

Results

According to Table 1, the variance analysis revealed a significant difference in the absorption of ultraviolet, visible, and infrared wavelengths emitted from both directions corono-apically and apico-coronally) in these three thicknesses ($p < .001$). Pairwise comparisons with Tukey's post hoc test showed that the ultraviolet wavelength's absorption rate in all three thicknesses is higher than visible and infrared light ($p < .001$). There are no significant differences between visible and infrared light absorption at three thicknesses ($p > .05$).

Table 1
Comparison of the absorption and transmission in radiation from above at ultraviolet, visible, and infrared wavelengths in each thickness

Tukey's post hoc test			P-value	Standard deviation ± Mean			Variable	Thickness
(3,2)	(3,1)	(2,1)		Infrared (3)	visible light (2)	Ultraviolet (1)		
0.992	< 0.001	< 0.001	< 0.001	0.41 ± 0.14	0.14 ± 0.42	1.30 ± 0.25	Absorption	300 μm
0.957	0.004	0.007	0.002	39.89 ± 13.50	37.87 ± 13.25	10.29 ± 5.87	Transmission	
0.976	< 0.001	< 0.001	< 0.001	0.42 ± 0.10	0.45 ± 0.12	1.58 ± 0.38	Absorption	600 μm
0.789	< 0.001	< 0.001	< 0.001	32.68 ± 6.99	35.34 ± 7.77	10.22 ± 3.43	Transmission	
0.969	< 0.001	< 0.001	< 0.001	0.40 ± 0.12	0.43 ± 0.12	1.47 ± 0.22	Absorption	1000 μm
0.939	0.035	0.019	0.014	28.99 ± 12.51	31.38 ± 14.01	8.69 ± 4.71	Transmission	

According to Table 2, there is also a significant difference in the rate of transmission of ultraviolet, visible, and infrared wavelengths emitted from both directions in these three thicknesses ($p < .001$). There is no significant difference between the transmission rates of visible and infrared light wavelengths ($p > .05$) in pairwise comparisons between wavelengths at any thickness. The lowest transmission is in the ultraviolet wavelength at 1000 μm.

Table 2
Comparison of absorption and transmission in radiation from below at ultraviolet, visible, and infrared light at each thickness

Tukey's post hoc test			P-value	Standard deviation ± Mean			Variable	Thickness
(3,2)	(3,1)	(2,1)		Infrared (3)	visible light (2)	Ultraviolet (1)		
0.968	< 0.001	< 0.001	< 0.001	0.55 ± 0.26	0.59 ± 0.26	1.35 ± 0.18	Absorption	300 µm
0.926	0.014	0.027	0.010	32.77 ± 12.95	30.27 ± 12.28	10.16 ± 4.06	Transmission	
0.957	< 0.001	< 0.001	< 0.001	0.43 ± 0.10	0.47 ± 0.11	1.61 ± 0.37	Absorption	600 µm
0.807	< 0.001	< 0.001	< 0.001	30.73 ± 6.68	33.24 ± 7.90	8.66 ± 3.44	Transmission	
0.915	< 0.001	< 0.001	< 0.001	0.45 ± 0.11	0.49 ± 0.09	1.46 ± 0.24	Absorption	1000 µm
0.911	0.034	0.016	0.012	26.58 ± 12.16	29.35 ± 13.18	7.17 ± 3.97	Transmission	

Figures 3 and 4 show more details about the difference in absorption amount in the radiation of the three wavelength's range of ultraviolet, invisible light, and infrared in three dentin thicknesses.

According to the results of Table 3, the independent t-test showed that the displacement of the angle of incidence in the absorption of ultraviolet, visible, and infrared wavelengths in all three thicknesses is insignificantly different, and one can state that it is statistically ineffective (p >.05)

In addition, figures 5 and 6 demonstrate more details about the difference in the amount of transmission between the three wavelengths of ultraviolet, invisible light and infrared in three dentin thicknesses.

Table 3 Comparison of the angle of incidence in the absorption rate of ultraviolet, visible, and infrared wavelengths in all thicknesses

P-value	Standard deviation Mean ±	Direction of radiation	Spectrum of the light	Thicknesses
0.738	1.30 ± 0.25	Corono-apical	Ultraviolet	300 μm
	1.305 ± 0.18	Apico-coronal		
0.249	0.42 ± 0.14	Corono-apical	visible light	
	0.59 ± 0.26	Apico-coronal		
0.323	0.41 ± 0.14	Corono-apical	Infrared	
	0.55 ± 0.26	Apico-coronal		
0.907	1.58 ± 0.38	Corono-apical	Ultraviolet	600 μm
	1.61 ± 0.37	Apico-coronal		
0.782	0.45 ± 0.12	Corono-apical	visible light	
	0.47 ± 0.11	Apico-coronal		
0.861	0.42 ± 0.10	Corono-apical	Infrared	
	0.43 ± 0.10	Apico-coronal		
0.907	1.47± 0.22	Corono-apical	Ultraviolet	1000 μm
	1.46 ± 0.24	Apico-coronal		
0.401	0.43 ± 0.12	Corono-apical	visible light	
	0.49 ± 0.09	Apico-coronal		
0.571	0.40 ± 0.12	Corono-apical	Infrared	
	0.45 ± 0.11	Apico-coronal		

As Table 4 shows, the independent t-test showed that the changes of radiation's incidence in the transmission rate in ultraviolet, visible, and infrared light wavelengths in all three thicknesses differ insignificantly and are statistically ineffective ($p > .05$).

Table 4
Comparison of the angle of incidence in the wavelength transmission of ultraviolet, visible, and infrared light in all thicknesses

P-value	Standard deviation Mean ±	Direction of radiation	Spectrum of the light	Thicknesses
0.969	10.29 ± 5.87	Corono-apical	Ultraviolet	300 µm
	10.16 ± 4.06	Apico-coronal		
0.276	37.84 ± 13.25	Corono-apical	visible Light	
	30.27 ± 12.28	Apico-coronal		
0.420	39.89 ± 13.50	Corono-apical	Infrared	
	32.7 ± 12.95	Apico-coronal		
0.494	10.22 ± 3.43	Corono-apical	Ultraviolet	600 µm
	8.66 ± 3.44	Apico-coronal		
0.682	35.34 ± 7.77	Corono-apical	visible light	
	33.24 ± 7.90	Apico-coronal		
0.661	32.68 ± 6.99	Corono-apical	Infrared	
	30.73 ± 6.68	Apico-coronal		
0.597	8.69 ± 4.71	Corono-apical	Ultraviolet	1000 µm
	7.17 ± 3.97	Apico-coronal		
0.821	31.38 ± 14.01	Corono-apical	visible light	
	29.35 ± 13.18	Apico-coronal		
0.766	28.99 ± 12.51	Corono-apical	Infrared	
	26.58 ± 12.16	Apico-coronal		

Discussion

The purpose of the study was to compare the transmission of light radiation in the ultraviolet to infrared wavelength range in three dentin thicknesses. This experimental laboratory study with a descriptive-analytical approach was carried out on 15 tooth specimens with a thickness of 300, 600, and 1000 µm and five samples from each section after disinfection. Ultraviolet, visible, and infrared wavelengths were irradiated from above (corono-apical) and below (apico-coronal).

The penetration of light radiation through dentin specimens depends on tissue's optical properties, chromophores such as melanin, hemoglobin, and water, the technical specifications of the device, and the operation method [37, 41]. Furthermore, another study considered the increase in transfer rate in enamel to dentin with differences in refractive indices coefficients related to light extensions [31].

Gutknecht et al. studied the antibacterial effect of 445 nm blue diode laser in root canal dentin on Enterococcus faecalis in human teeth at three thicknesses of 300, 500 and 1000 μm, and showed the effectiveness of blue diode laser in the appropriate radiation parameter [19].

For this reason, we employed three dentin thicknesses to investigate the kinetic of absorption and light transmission in the aforementioned wavelengths.

Dogandzhiyska et al. [37] measured the absorption and penetration of light in the wavelength range 350-1000 nm on dentin specimens with a thickness of 1 mm prepared from above the roof of the pulp chamber perpendicular to the longitudinal axis of the tooth. They reported that the highest tissue uptake in radiation was observed in the blue spectral region and the lowest in the infrared spectral range. Therefore, the lower the absorption of light with a specific wavelength to the dentin, the greater its transmission.

In contrast, in our study, dentin samples were used with three different thicknesses of 300, 600, and 1000 μm in a broader light spectrum of 190 to 1100 nm. The samples were cut transversely only from the chamber pulp's roof perpendicular to the longitudinal axis of the tooth for matching. Nonetheless, our study indicated that the transmission and absorption of the wavelength spectrum of Ultraviolet range was significantly different with visible and infrared light wavelengths ($p >.001$).

Moreover, some studies have evaluated the optical properties of the diffusion of light through the dentin and enamel. Zijp et al. [42] in a theoretical model, irradiated 16 μm thin layers of dentin cut parallel to the tubules with He-Ne laser light at various angles to determine the light transmission in the vertical and parallel directions to the dentin tubules. They concluded that dentin tubules are directly involved in the scattering of light on this tissue. When the light was applied parallel to the dentin tubule, the dentin's transmission was more intense. On the other hand, light perpendicular to the dentin tubule axis further reduced its intensity (referring to dentin's anisotropic properties). These data suggest that transcendental transmission of laser light occurs, at least partly, through dentin tubules.

Masayuki O. et al. (2010) conducted a study entitled “Transmission and passage of laser light through dentin” using a laser with a wavelength of 805 ± 20 nm and on the one-millimeter disks of dentin, half of which had been prepared perpendicular to the longitudinal axis of the tooth and half parallel to that. The study found that the laser beam transmission in sections perpendicular to the dentinal tubules was two and a half times the sections prepared parallel to tubules [23].

In another study, Vaarkamp et al. prepared various sections and examined 15 enamel and 15 dentin specimens with parallel and perpendicular incisions of the proximal teeth with a thickness of approximately 0.03 ± 0.85 mm and the light transmission using the He-Ne laser light source (633 nm) by changing the radiation angle. Their study showed the ability to transmit light through dentinal tubules with a high refractive index and is based on the internal reflection through peri-tubular dentin [43].

In this study, to simulate the clinic conditions of radiations during dental treatments like endodontics and bleaching, the beams were radiated in both the corono-apically and apico-coronally directions due to inconsistency in the existing dentin tubules. The thickness of the discs could, however, eliminate the anisotropic properties of the specimens in some extent, so dentin discs with thicknesses of 0.3, 0.6, and 1 mm were used. Nevertheless, the results could not be directly referred to the findings obtained through radiating the beams to dentin discs from proximal area of the teeth or thicker dentin discs [42, 43].

In our study, two factors are considered important to justify the weaker association between the permeability of the dentin and the attenuation and distribution of light. First, the dentin discs were cut from the upper part pulp chamber and the aperture of dentin tubules is wider at this distance. The second and main factor relates to the direction of radiation which was along the dentin tubules from corono-apical or apico-coronal sides. The results of this study indicated that the applied radiation protocol based on which the angle of radiation and dentin cross section were matched from one sample to another did not interfere with trans-dentinal light transmission.

There is a possibility that the temporary difference in the number and diameter of the tubules could interfere in the transmission of light, but no study has yet reported the significant effects of these factors on light distribution through the structure of dentin. Therefore, it might be assumed that the number and diameter of tubules could assist the light distribution, though this could not be statistically significant. For this reason, there was no direct relationship between dentin permeability and the attenuation of trans-dentinal light. Moreover, it seems that washing the surface of dentin with EDTA before the permeability experiment was important as the open apertures of tubules facilitate light transmission. Smear layer, which consists of mineral debris and is the outcome of cutting and rinsing, could reduce 86% of the dentin's permeability [44].

In another study, Kienle et al.[30] provided dentin discs with 1-3 mm thickness from the upper part of the pulp chamber. Also, they investigated the HeNe laser light transmission with 633 nm wavelength through the inter-tubular dentin which mainly consisted of collagen fibers and hydroxyapatite crystals. The amount of light in dentin discs cleaned with EDTA reduced by 2% (from 61–59%) in comparison with the discs covered by smear layer. This result shows that, under the experimented conditions and parameters of LED, the existence of smear layer does not have a remarkable role per se in the reduction of trans-dentinal light transmission. This finding was confirmed in the present study as the attenuation of light was not influenced after changing the direction of radiation despite the removal of smear layer formed on the two sides (pulpal and occlusal) of the disc, indicating the capability of light distribution through dentin tubules.

Conclusion

According to the results of this study, the amount of beam absorption and distribution of infrared and invisible light wavelength was the same for the three thicknesses of 300, 600, and 1000 mm. The ultraviolet wavelength had the lowest transmission and highest absorption in dentin and this was statistically significant. Although changing the direction of radiation does lead to significant differences in the amount of transmission and absorption at ultraviolet, invisible light, and infrared wavelengths for the three thicknesses, it could be clinically important due to variety in treatment protocols; therefore, more studies need to be undertaken.

Declarations

Acknowledgment:

The study was conducted with register number 111131 and ethics code IR.GOUMS.REC.1398.212 in the dental research center of Golestan University of Medical Sciences, Iran.

Authors' contribution:

dr Elmira Eslami and dr. Ezatolah Kazeminejad wrote the main manuscript text and dr. Kazeminejad also prepared figures. And Azizeh karimian analyzed statistics and wrote the Result part of the article.

Conflict of interest:

The authors declare that they have no conflict of interest.

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Availability of data and materials:

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical approval:

This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent:

For this type of study, formal consent is not required.

References

1. Chandler NP, Pitt Ford TR and Monteith BD (2014) Laser light passage through restored and carious posterior teeth. J Oral Rehabil 41:630–4. doi: 10.1111/joor.12173
2. Hoffmann L, Feraric M, Hoster E, Litzenburger F and Kunzelmann K-H (2021) Investigations of the optical properties of enamel and dentin for early caries detection. Clinical Oral Investigations 25:1281–1289. doi: 10.1007/s00784-020-03434-x
3. Lee YK (2015) Translucency of human teeth and dental restorative materials and its clinical relevance. J Biomed Opt 20:045002. doi: 10.1117/1.Jbo.20.4.045002
4. Li T, Zhang X, Shi H, Ma Z, Lv B and Xie M (2019) Er:YAG laser application in caries removal and cavity preparation in children: a meta-analysis. Lasers Med Sci 34:273–280. doi: 10.1007/s10103-018-2582-x
5. Guidotti R, Merigo E, Fornaini C, Rocca JP, Medioni E and Vescovi P (2014) Er:YAG 2,940-nm laser fiber in endodontic treatment: a help in removing smear layer. Lasers Med Sci 29:69–75. doi: 10.1007/s10103-012-1217-x
6. Olivi M, Raponi G, Palaia G, Berlutti F, Olivi G, Valentini E, Tenore G, Del Vecchio A and Romeo U (2020) Disinfection of Root Canals with Laser-Activated Irrigation, Photoactivated Disinfection, and Combined Laser Techniques: An Ex Vivo Preliminary Study. Photobiomodulation, Photomedicine, and Laser Surgery 39:62–69. doi: 10.1089/photob.2020.4879
7. Shivakoti I, Kibria G, Cep R, Pradhan BB and Sharma A (2021) Laser Surface Texturing for Biomedical Applications: A Review. Coatings 11:124.
8. Sin JH-M, Walsh LJ, Figueredo CM and George R (2021) Evaluation of effectiveness of photosensitizers used in laser endodontics disinfection: A systematic review. Translational Biophotonics 3:e202000007. doi: https://doi.org/10.1002/tbio.202000007
9. Gupta S and Kumar S (2011) Lasers in Dentistry-An Overview. Trends Biomater Artif Organs 25:119–123.
10. Morsy DA, Negm M, Diab A and Ahmed G (2018) Postoperative pain and antibacterial effect of 980 nm diode laser versus conventional endodontic treatment in necrotic teeth with chronic periapical lesions: A randomized control trial. F1000Res 7:1795–1795. doi: 10.12688/f1000research.16794.1
11. Convissar RA and Ross G (2020) Photobiomodulation lasers in dentistry. Seminars in Orthodontics 26:102–106. doi: https://doi.org/10.1053/j.sodo.2020.06.005
12. Mylona V, Anagnostaki E, Parker S, Cronshaw M, Lynch E and Grootveld M (2020) Laser-Assisted aPDT Protocols in Randomized Controlled Clinical Trials in Dentistry: A Systematic Review. Dentistry Journal 8:107.
13. Schulte-Lünzum R, Gutknecht N, Conrads G and Franzen R (2017) The Impact of a 94P nm Diode Laser with Radial Firing Tip and Bare End Fiber Tip on Enterococcus faecalis in the Root Canal Wall Dentin of Bovine Teeth: An In Vitro Study. Photomedicine and laser surgery 35 7:357–363.
14. Nasher R, Hilgers RD and Gutknecht N (2020) Debris and Smear Layer Removal in Curved Root Canals Using the Dual Wavelength Er,Cr:YSGG/Diode 940 nm Laser and the XP-Endoshaper and

Finisher Technique. Photobiomodul Photomed Laser Surg 38:174–180. doi: 10.1089/photob.2019.4693

15. Ferreira LS, Diniz IMA, Maranduba CMS, Miyagi SPH, Rodrigues M, Moura-Netto C and Marques MM (2019) Short-term evaluation of photobiomodulation therapy on the proliferation and undifferentiated status of dental pulp stem cells. Lasers Med Sci 34:659–666. doi: 10.1007/s10103-018-2637-z
16. Kulkarni S, Meer M and George R (2019) Efficacy of photobiomodulation on accelerating bone healing after tooth extraction: a systematic review. Lasers Med Sci 34:685–692. doi: 10.1007/s10103-018-2641-3
17. Alves FAM, Marques MM, Cavalcanti SCSXB, Pedroni ACF, Ferraz EP, Miniello TG, Moreira MS, Jerônimo T, Deboni MCZ and Lascala CA (2020) Photobiomodulation as adjunctive therapy for guided bone regeneration. A microCT study in osteoporotic rat model. Journal of Photochemistry and Photobiology B: Biology 2020;213:112053.
18. doi: https://doi.org/10.1016/j.jphotobiol.2020.112053
19. Katalinić I, Budimir A, Bošnjak Z, Jakovljević S and Anić I (2019) The photo-activated and photo-thermal effect of the 445/970 nm diode laser on the mixed biofilm inside root canals of human teeth in vitro: A pilot study. Photodiagnosis Photodyn Ther 26:277–283. doi: 10.1016/j.pdpdt.2019.04.014
20. Gutknecht N, Al Hassan N, Martins MR, Conrads G and Franzen R (2018) Bactericidal effect of 445-nm blue diode laser in the root canal dentin on Enterococcus faecalis of human teeth. Lasers in Dental Science 2:247–254. doi: 10.1007/s41547-018-0044-1
21. Kim HK, Kim JH, Abbas AA, Kim DO, Park SJ, Chung JY, Song EK and Yoon TR (2009) Red light of 647 nm enhances osteogenic differentiation in mesenchymal stem cells. Lasers Med Sci 24:214–22. doi: 10.1007/s10103-008-0550-6
22. Bago I, Plecko V, Gabrić D, Schauperl Z, Baraba A and Anić I (2012) Antimicrobial efficacy of high-power diode laser, photo-activated disinfection, conventional and sonic activated irrigation during root canal treatment. International endodontic journal 46. doi: 10.1111/j.1365-2591.2012.02120.x
23. Lukač N and Jezeršek M (2018) Amplification of pressure waves in laser-assisted endodontics with synchronized delivery of Er:YAG laser pulses. Lasers in medical science 33:823–833. doi: 10.1007/s10103-017-2435-z
24. Otsuki M, Kijima M and Tagami J (2010) Transmission of Diode Laser through Dentin. Journal of Japanese Society for Laser Dentistry 21:18–21. doi: 10.5984/jjpnsoclaserdent.21.18
25. Nakajima M, Arimoto A, Prasansuttiporn T, Thanatvarakorn O, Foxton RM and Tagami J (2012) Light transmission characteristics of dentine and resin composites with different thickness. J Dent 40 Suppl 2:e77-82. doi: 10.1016/j.jdent.2012.08.016
26. Hariri I, Sadr A, Shimada Y, Tagami J and Sumi Y (2012) Effects of structural orientation of enamel and dentine on light attenuation and local refractive index: an optical coherence tomography study. J Dent 40:387–96. doi: 10.1016/j.jdent.2012.01.017

27. Surmelioglu D and Usumez A (2020) Effectiveness of Different Laser-Assisted In-Office Bleaching Techniques: 1-Year Follow-Up. Photobiomodul Photomed Laser Surg 38:632–639. doi: 10.1089/photob.2019.4741
28. Méndez Romero JM, Villasanti Torales UA and Villalba Martínez CJ (2020) Efficacy of laser application in dental bleaching: A randomized clinical controlled trial. Am J Dent 33:79–82.
29. Chen CL, Parolia A, Pau A and Celerino de Moraes Porto IC (2015) Comparative evaluation of the effectiveness of desensitizing agents in dentine tubule occlusion using scanning electron microscopy. Aust Dent J 60:65–72. doi: 10.1111/adj.12275
30. Moeintaghavi A, Ahrari F, Nasrabadi N, Fallahrastegar A, Sarabadani J and Rajabian F (2021) Low level laser therapy, Er,Cr:YSGG laser and fluoride varnish for treatment of dentin hypersensitivity after periodontal surgery: A randomized clinical trial. Lasers Med Sci. doi: 10.1007/s10103-021-03310-4
31. Kienle A, Michels R and Hibst R (2006) Magnification–a new look at a long-known optical property of dentin. J Dent Res 85(10):955–9. doi: 10.1177/154405910608501017
32. Uusitalo E, Varrela J, Lassila L and Vallittu PK (2016) Transmission of Curing Light through Moist, Air-Dried, and EDTA Treated Dentine and Enamel. Biomed Res Int 2016:5713962. doi: 10.1155/2016/5713962
33. Chandler NP, Pitt Ford TR and Watson TF (2001) Pattern of transmission of laser light through carious molar teeth. International Endodontic Journal 34:526–532. doi: https://doi.org/10.1046/j.1365-2591.2001.00428.x
34. Odor TM, Chandler NP, Watson TF, Ford TR and McDonald F (1999) Laser light transmission in teeth: a study of the patterns in different species. Int Endod J 32:296–302. doi: 10.1046/j.1365-2591.1999.00224.x
35. Schmid F (2001) Biological Macromolecules: Uv visible Spectrophotometry. Book title.,
36. Roberts J, Power A, Chapman J, Chandra S and Cozzolino D (2018) The Use of UV-Vis Spectroscopy in Bioprocess and Fermentation Monitoring. Fermentation 4:18.
37. Zain MNM, Yusof ZM, Yazid F, Ashari A, Wong KSH, Lee WJ, Tan KF, Ariffin SHZ and Wahab RMA (2020) Absorption spectrum analysis of dentine sialophosphoprotein (DSPP) in orthodontic patient. AIP Conference Proceedings 2203:020007. doi: 10.1063/1.5142099
38. Dogandzhiyska V, Angelov I, Dimitrov S and Uzunov T (2015) In Vitro Study of Light Radiation Penetration Through Dentin, According to the Wavelength. Acta Medica Bulgarica 42. doi: 10.1515/amb-2015-0013
39. Titley KC, Chernecky R, Rossouw PE and Kulkarni GV (1998) The effect of various storage methods and media on shear-bond strengths of dental composite resin to bovine dentine. Arch Oral Biol 43:305–11. doi: 10.1016/s0003-9969(97)00112-x
40. Mobarak EH, El-Badrawy W, Pashley DH and Jamjoom H (2010) Effect of pretest storage conditions of extracted teeth on their dentin bond strengths. J Prosthet Dent 104:92–7. doi: 10.1016/S0022-3913(10)60098-4

41. Darda S, Madria K, Jamenis R, Heda A, Khanna A and Sardar L (2014) An in-vitro evaluation of effect of EDTAC on root dentin with respect to time. J Int Oral Health 6:22–27.
42. Tunér J and Hode L (2010) The new laser therapy handbook: a guide for research scientists, doctors, dentists, veterinarians and other interested parties within the medical field. Prima Books, Grängesberg
43. Zijp JR and Bosch JJ (1993) Theoretical model for the scattering of light by dentin and comparison with measurements. Appl Opt 32:411–5. doi: 10.1364/ao.32.000411
44. Vaarkamp J, ten Bosch JJ and Verdonschot EH (1995) Propagation of light through human dental enamel and dentine. Caries Res 29:8–13. doi: 10.1159/000262033
45. Marijnissen JPA and Star WM (1987) Quantitative light dosimetry in vitro and in vivo. Lasers in Medical Science 2:235–242. doi: 10.1007/BF02594166

Figures

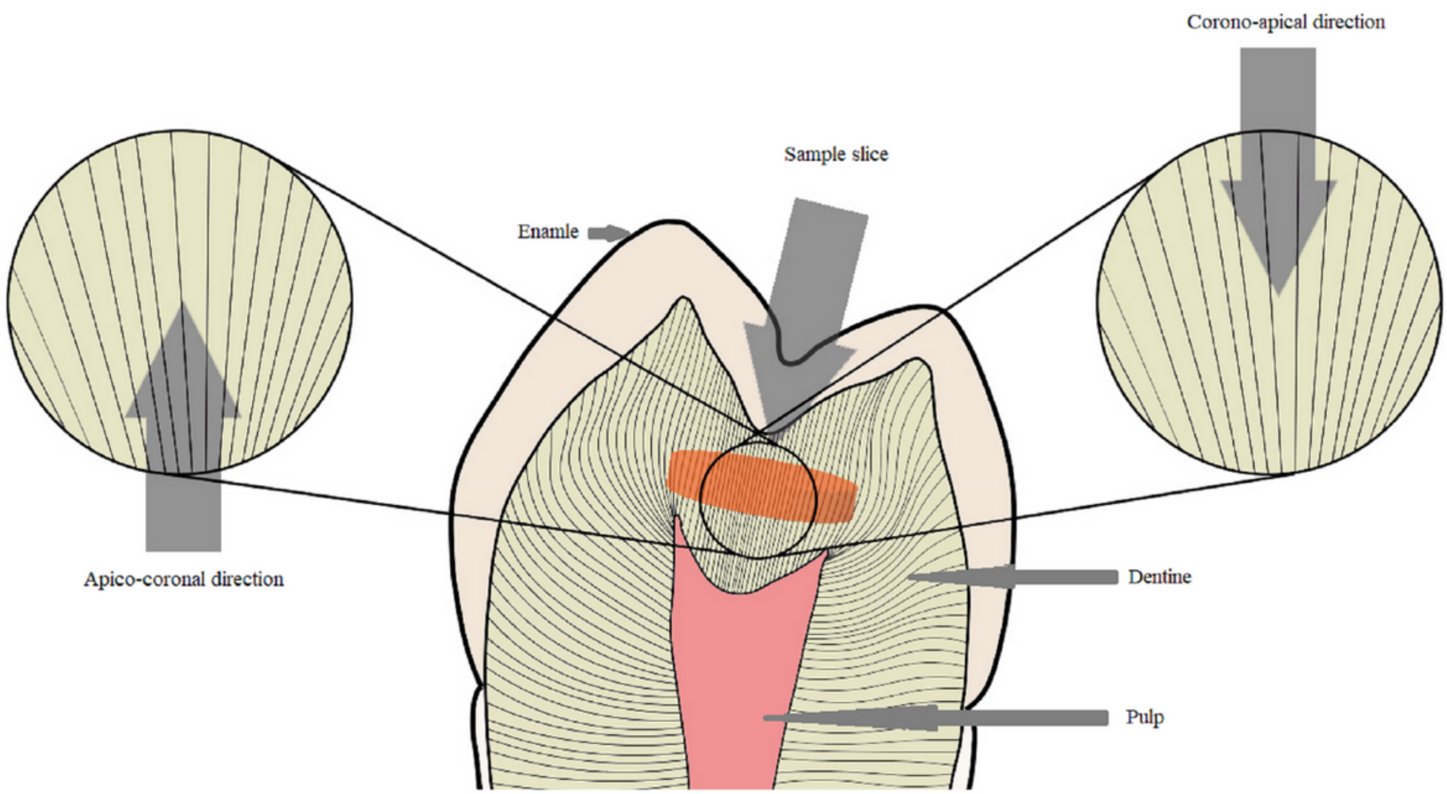

Figure 1

Schematic illustration of human molar dentine disk showing the tubular course prepared and both direction of beam irradiation

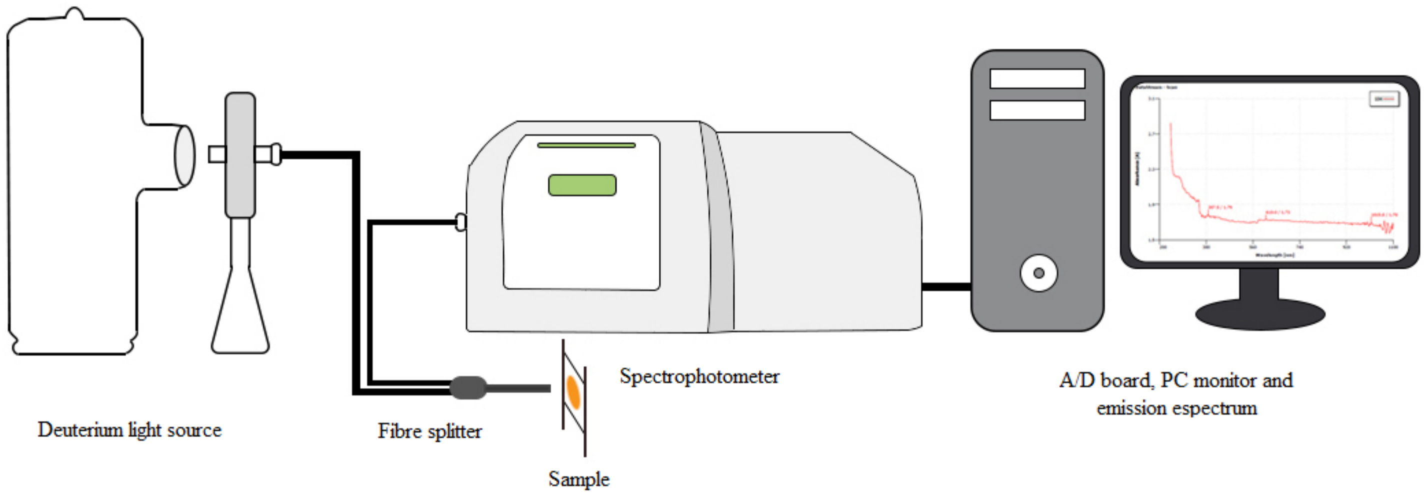

Figure 2

Schematic illustration of experimental set-up used in measurement of the absorption and transmittance on the dentinal disks

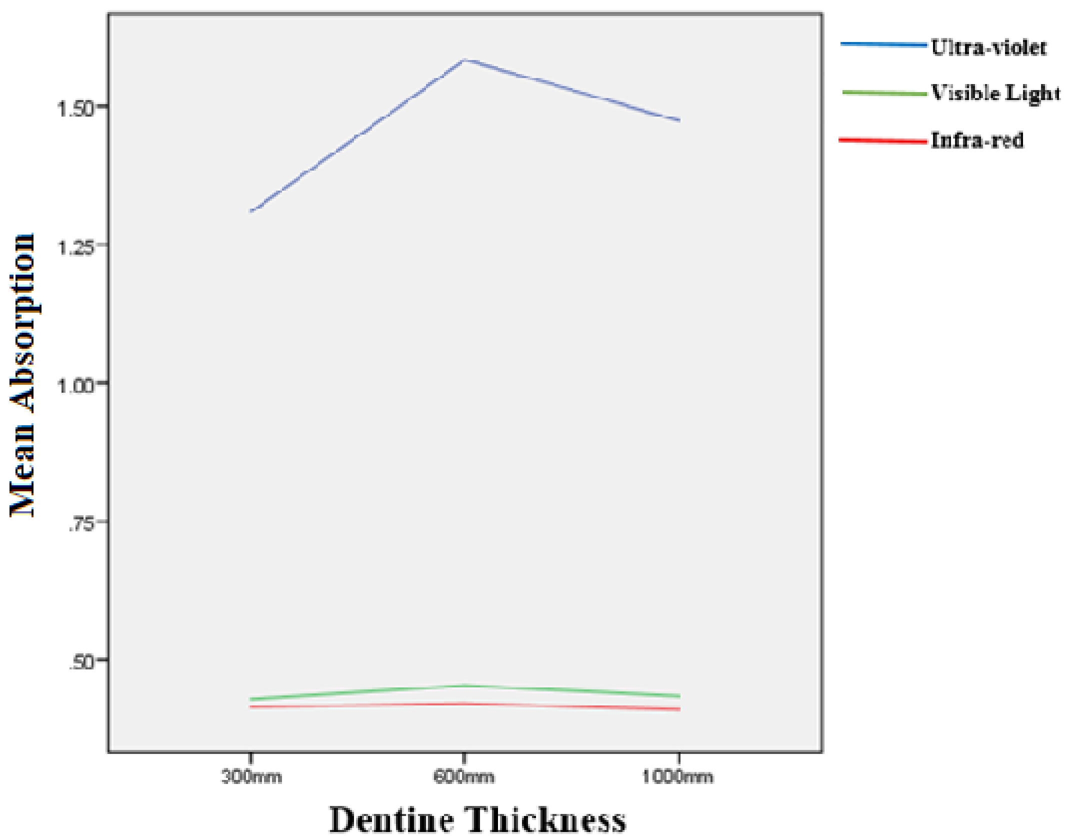

Figure 3

Comparison of absorption in radiation from above in ultraviolet, visible and infrared light wavelengths in each thickness

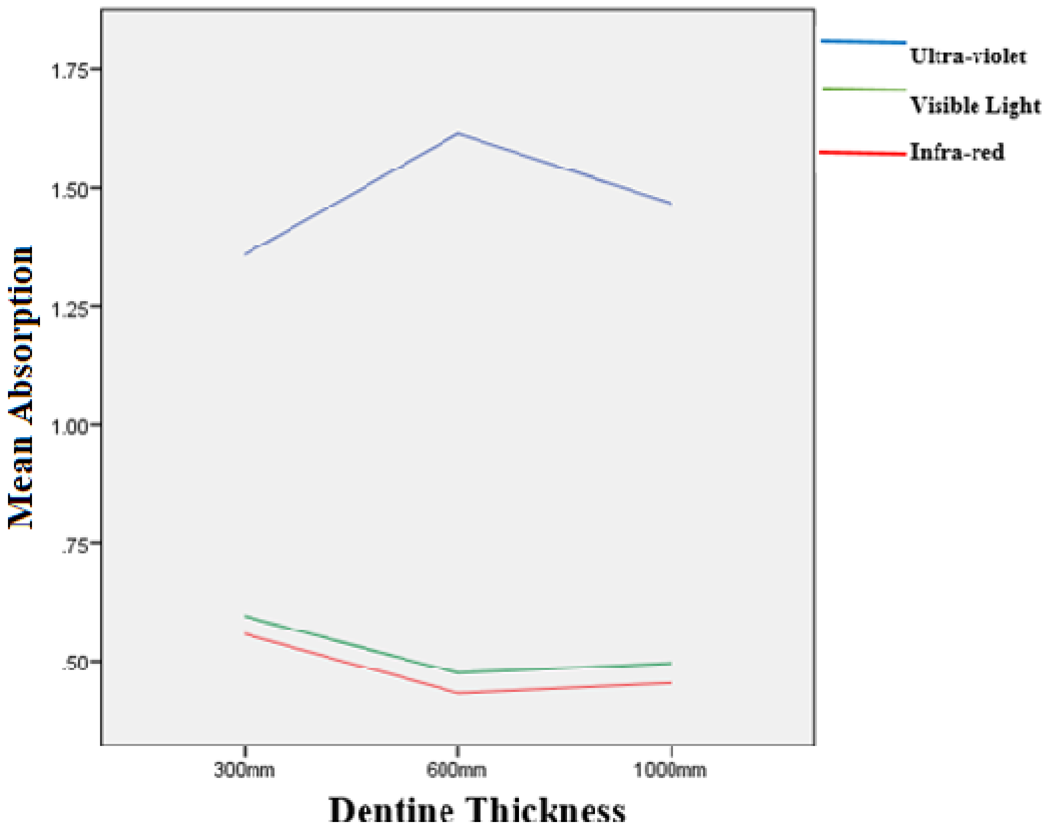

Figure 4

Comparison of absorption in radiation from below ultraviolet, visible and infrared wavelengths in all thickness

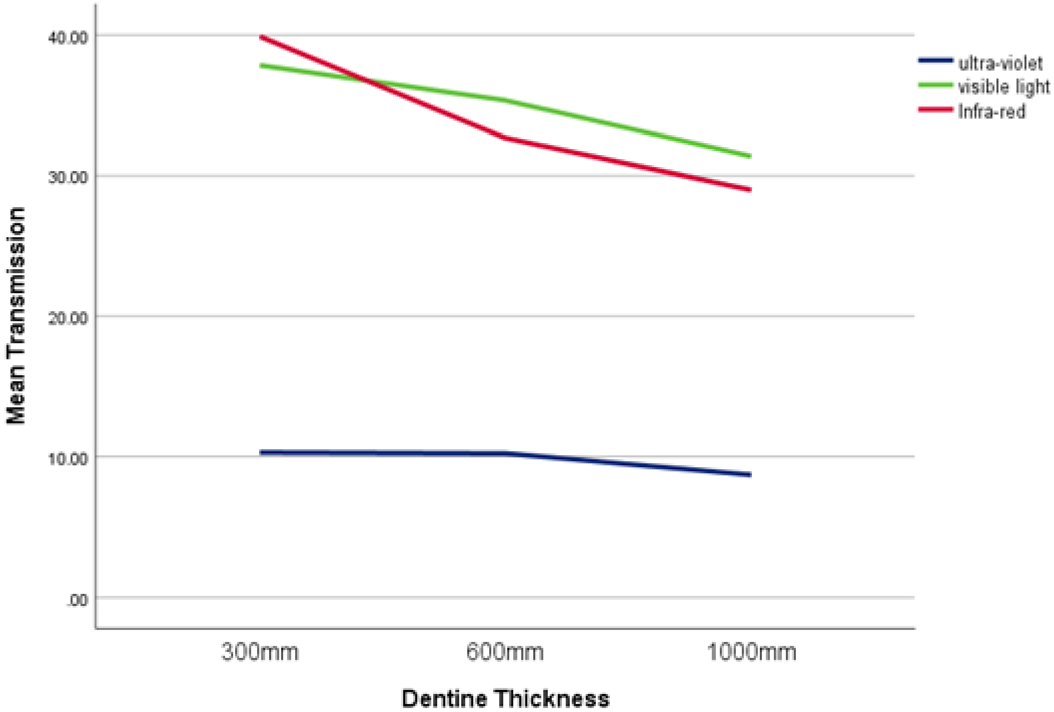

Figure 5

Comparison of transmission in radiation from above in ultraviolet visible and infrared tight wavelengths in each thickness

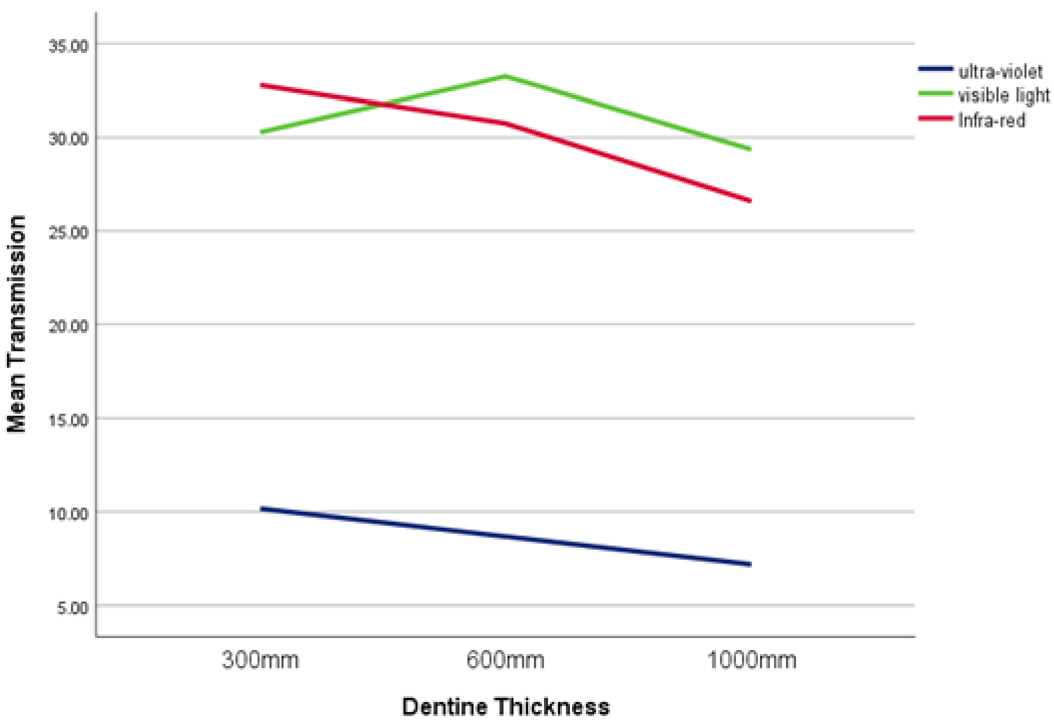

Figure 6

Comparison of transmission in radiation from below at ultraviolet visible and infrared light wavelengths in each thickness