

## Treatment of toe nail fungus infection using an AO Q-switched eye-safe erbium glass laser at 1534nm

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### ABSTRACT

We report on “eye-safe” erbium glass laser operating at **Short-Wave Infra-Red (SWIR)** region at 1534nm, to treat Onychomycosis or toenail fungus. Infected toenails of 12 patients were treated over a 3 month period using both long pulse and Q-switched laser output pulses. Our results compared favorably to Neodymium Yttrium Aluminum Garnet (Nd:YAG) laser fungus treatment studies as reported in literature. Nd:YAG laser devices, operating in the **Near Infra-Red, (NIR)** region at 1064nm, have recently become an effective alternative treatment to traditional oral medications used to treat nail fungal infections. Conventional nail infection treatments employ medications such as allylamines, azoles and other classes of antifungal drugs that are unpopular due to numerous side-affects and drug interactions. Side-effects of these drugs include headache, itching, loss of sense of taste, nausea, diarrhea, heart failure and even potential death from liver failure [1,2,3]. The effectiveness of conventional oral antifungal medications varies. In addition, antifungal prescription drugs are administered for long periods ranging from 6 weeks to 18 months. Nd:YAG antifungal laser treatment reports claim high success rates (65-95%) in eradicating toenail fungus and without adverse side-affects. Multiple laser treatments are administered over a 3 to 6 month period [4,5,6,7]. Our initial treatments performed with the Er:glass laser on toenail fungus patients required only 1 to 2 treatments for cure. This same SWIR laser was used in experiments to treat Athlete's Foot fungal infections. The 1534nm Er:glass laser emission has been found to be well optimized for dermatological treatments due high transmission properties of human skin in the SWIR region. Increased depth of tissue penetration is well-tolerated and provides for effective treatment of various skin conditions. [8,9,10,11] “Eye-safe” Class I lasers provide for practical skin and nail tissue treatment without the need for eye-protection goggles. Laser safety filters may inhibit a practitioner's vision and ability to distinguish skin and nail regions exhibiting different colors and textures. The laser is “eye-safe” due to the fact that Megawatt peak power Q-switched lasers operating at 1.54um in the narrow spectral window between 1.4um and 1.6um are approximately 8000 times more eye-safe than other laser devices operating in the visible and near infrared. Long-pulse or free running lasers operating in this wavelength range are ~ 2000 times more eye-safe [12].

**Key Words:** Laser toenail fungus treatment, Er:glass laser, Nd:YAG laser, Treatment of Onychomycosis, Toenail fungus  
Eye-safe laser, Laser dermatology, Erbium glass laser

### 1. INTRODUCTION

Onychomycosis is a tenacious fungal infection of the nail bed that typically affects adult toenails [13-16]. Mycoses is the term for a fungal infection of humans and animals. A cutaneous mycoses is a fungal infection that extends deeper into the epidermis, including the hair and nails. The infection is typically restricted to the keratinized layers of the skin, hair, and nails. This type of fungal infection is also referred to as ringworm (even though there is no worm involved). Another common skin disease is the athlete's foot. This is a fungal infection often affecting the region between the toes.

It is divided into three categories: chronic interdigital athlete's foot, chronic scaly athlete's foot, and acute vesicular athlete's foot.

Conventional nail fungus infection treatment employs medications such as allylamines, azoles and other classes of antifungal drugs. These drugs are unpopular due to numerous side-effects and drug interactions. Side-effects of nail fungus drugs include headache, itching, loss of sense of taste, nausea, diarrhea, heart failure and even potential death from liver failure. Treatment of athlete's foot involves regular applications of topical medications and severe athlete's foot fungal infections are treated with oral antifungal medications. In general, there are limited "highly effective" treatment options for nail and skin fungal infections. Recent laser treatments of onychomycosis using Nd:YAG lasers operating at the Near InfraRed (NIR) wavelength of 1064nm have been shown to be an effective alternative to conventional treatment [4,5,7]. Dermatological lasers operating in the Short Wave InfraRed (SWIR) between 1400-1600nm region are often used for the removing wrinkles and acne scars. The superior effectiveness of non-Q-switched NIR and SWIR lasers in aesthetic dermatological procedures is apparently due their ability to provide greater penetration of skin tissue when compared to visible laser wavelengths. Optical transmission spectra for human skin and nail tissues increase with longer wavelength radiation. This is illustrated in figures 1, 2 and 3 below. The curves indicate that with longer laser wavelengths extending from the visible through the NIR and SWIR region we can expect deeper light penetration though the skin tissue or nail bed, providing more effective treatment of the fungal infection [17-23].

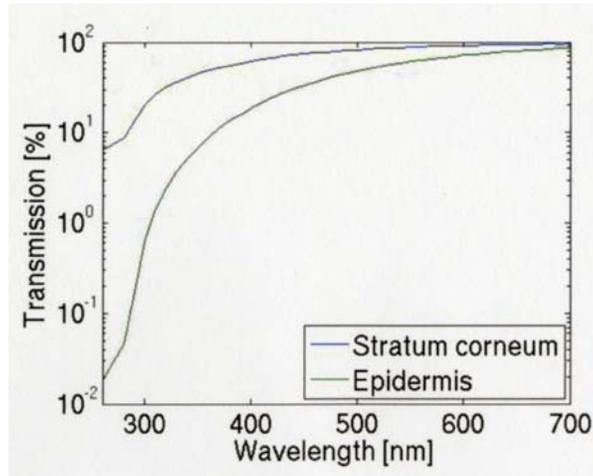


Figure 1. Spectral transmission of the stratum corneum (upper curve) and of the entire epidermis (lower curve) in the wavelength regions UVB, UVA and visible light corresponding to skin type III or IV [18].

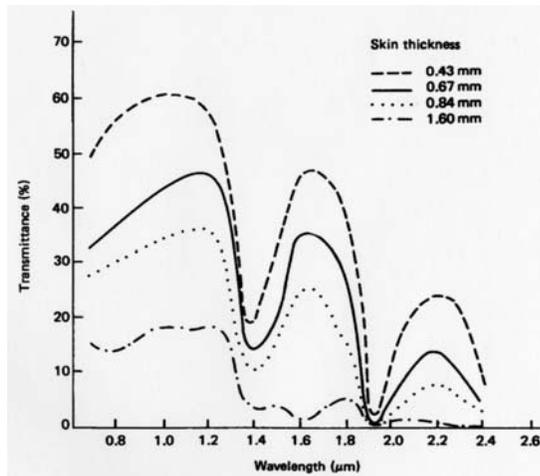


Figure 2. Spectral transmission of excised white human breast skin [22].

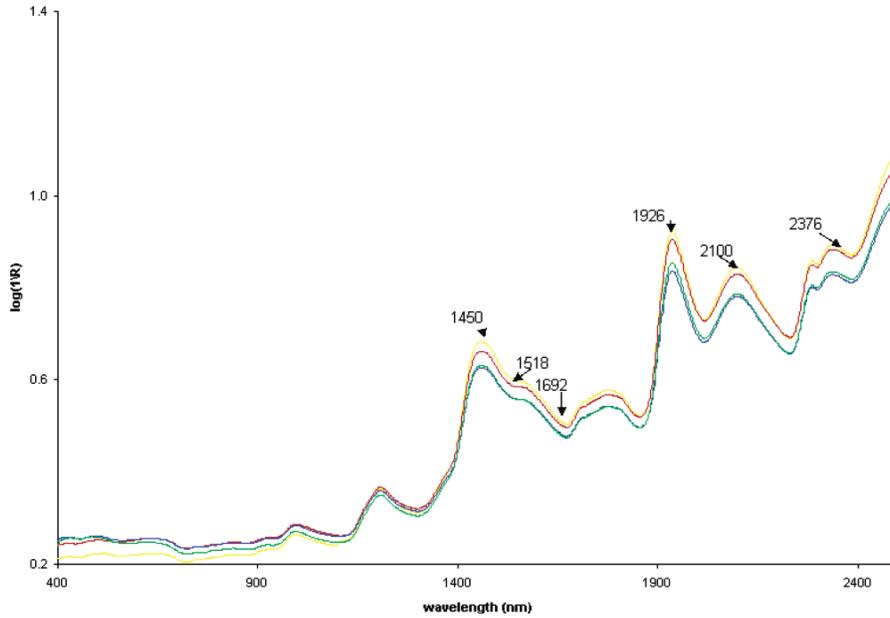


Figure 3. NIR-vis reflectance spectra for fusarial fungal infections [24].

Absorption spectra of mycotoxin fusarium fungi show an increased absorption in the short wave infrared region (1400 – 3000nm [25]). Increased nail tissue absorption in the SWIR due to an onychomycosis fungal infection may provide for a more effective treatment when compared to NIR or visible light applications[26, 27]. This is illustrated in the spectra shown in figure 4.

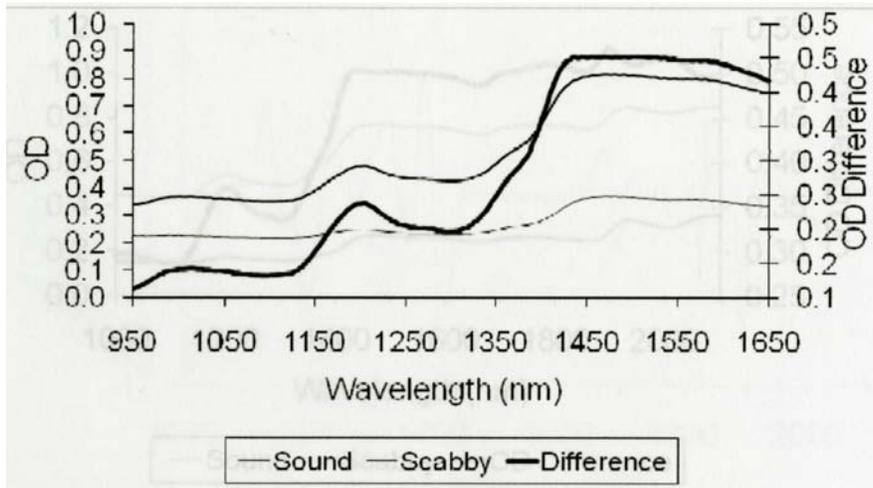


Figure 4. NIR-SWIR absorption spectra for fusarium fungal infection [26].

The transmission spectra shown in figure 5, illustrates a comparison of NIR and SWIR absorption for yeast fungi. The 1534nm Er:glass laser emission corresponds to a higher absorption (lower transmission value) than the 1064nm Nd:YAG laser emission. This increased absorption at 1534nm for fungi coupled with a higher depth of penetration in human skin and nail tissues helps to explain why only one or two treatments were found necessary for effective Er:Glass laser treatment when compared to 4 to 6 treatments using the Nd:YAG laser [4,5,7].

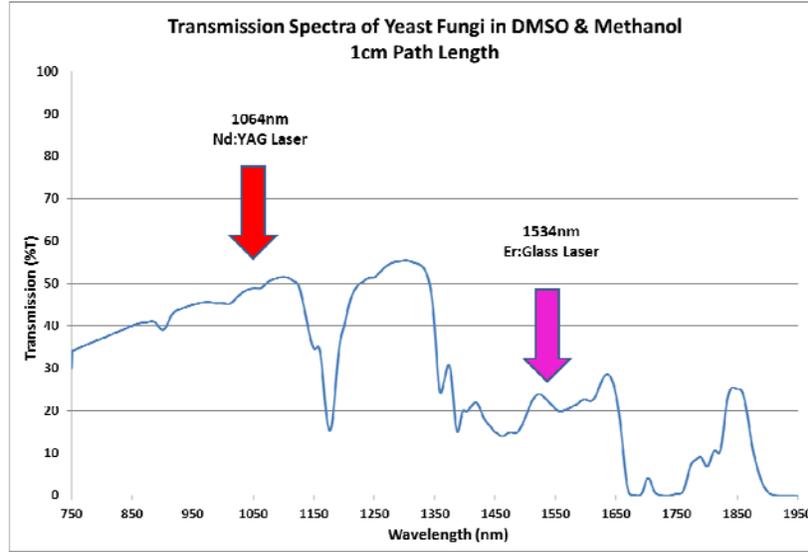


Figure 5. NIR-SWIR transmission spectra for yeast fungi in DMSO and water [31].

## 2. INSTRUMENTATION

Nail treatment was applied with a Kigre model AO-1010 erbium glass laser head operating at 1534nm. A modified model HESP-E-AO-PS laboratory power supply (including an Acusto-Optic Q-switch driver) allowed the practitioner to select and deliver 1mm beam diameter pulses either short Q-switched (6ns) or “long pulses” free running (3ms). The laser produced ~ 15mj/pulse in Q-switch mode and ~ 100mj/pulse in free running mode. A foot switch triggered the start and stop of laser operation. Pulse repetition rate options included single shot, 3Hz and 5Hz. An image of the AO-1010 laser head (mounted on gun hand grip) and the laboratory power supply front panel is shown in figure 6.



Figure 6. AO-1010 laser head (mounted on paintball gun grip) and laboratory power supply front panel [28,29,30].

In addition to the SWIR laser, we employed during this investigation a Jasco model V-670 spectrophotometer and quartz cuvette to record transmission spectra. A Leitz, Ergolux microscope and Panasonic GP-KR222 color digital camera was employed to capture micrographs of stained fungus. Toenail pictures were taken with a Canon SX110 digital camera. A 20mW RGLase 488nm semiconductor laser was used for dye excitation.

### 3. MATERIALS & METHODS

The effectiveness of the 1534nm laser was evaluated through the use of a yeast fungus viability kit capable of distinguishing live and dead yeast. The kit included a green-fluorescent nucleic acid, and red-fluorescent nucleic acid dye in propidium iodide. The dyes differ in color and ability to penetrate healthy yeast cells. The red stain penetrates only yeast with damaged membranes and produces a red fluorescence emission. The green stain penetrates yeast with intact cell membranes and produces a green fluorescence emission. The excitation/emission maxima for the dyes is 480/500 nm for the green stain and 490/635 nm for the red stain. Micrographs (under 488nm excitation) of live yeast fungi before and after laser treatment are shown below in figure 7 and 8.

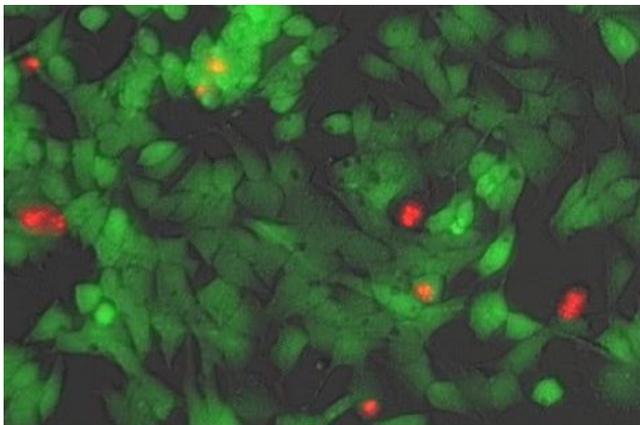


Figure 7. Live/dead yeast micrograph before treatment with 1534nm laser.

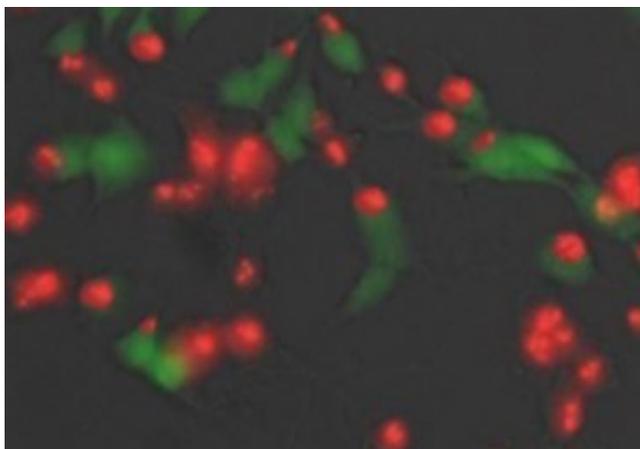


Figure 8. Live/dead yeast micrograph after treatment with 1534nm laser.

Initial treatment included both Q-switched & long pulse laser pulses. Both (long pulse and Q-switched) treatments were applied to patient #1 (adult female, 69) and patient #2 (adult male, 58) using single shot, 1Hz, 3Hz and 5Hz pulse repetition rates. A comparison of the effectiveness of the two treatment options indicated more efficient results with the use of (3ms) long pulse laser setting. The longer pulses killed the fungus more efficiently and provided for better nail tissue surface penetration than the alternative Q-switch short pulse (6ns) laser setting. The 3ms long pulse laser output setting was applied for the remainder of this study.

12 patients between the ages of 56 and 83 years of age treated and observed over a 7 month period. Subjects exhibited mild to severe onychomycosis fungal infection on one or more toenail. A 50mm standoff between the laser output

window and the targeted nail surface was used to insure a consistent power density and laser energy/pulse dosage. Laser pulses (~ 2mm beam diameter) were applied across the entire nail surface in a matrix pattern to insure uniform coverage. No anesthesia was applied or deemed necessary as the long pulse laser output did not induce significant discomfort.

#### 4. RESULTS

The recording of initial and follow-up toe nail images are shown below in figures 9, 10 and 11. Patients #4 through #12 each received one treatment. Patient #2 and #3 received two treatments each. Patient #1 received three treatments total. Example progress photos shown below cover a period of no more than 6-months from the time of their initial laser treatment. All of the patients responded well to treatment and are expected to be completely free of toe nail fungal infection after ~12 month period when the entire nail is replaced with new growth.

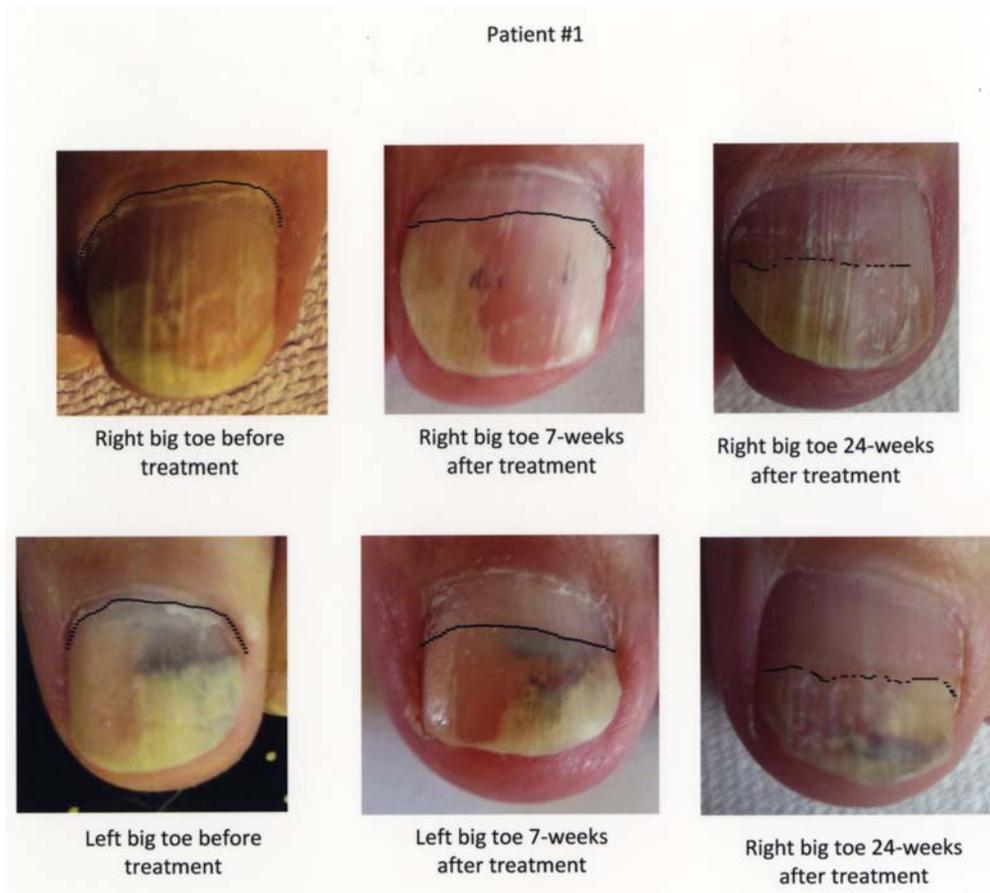


Figure 9. Patient #1 (adult female, age 69)

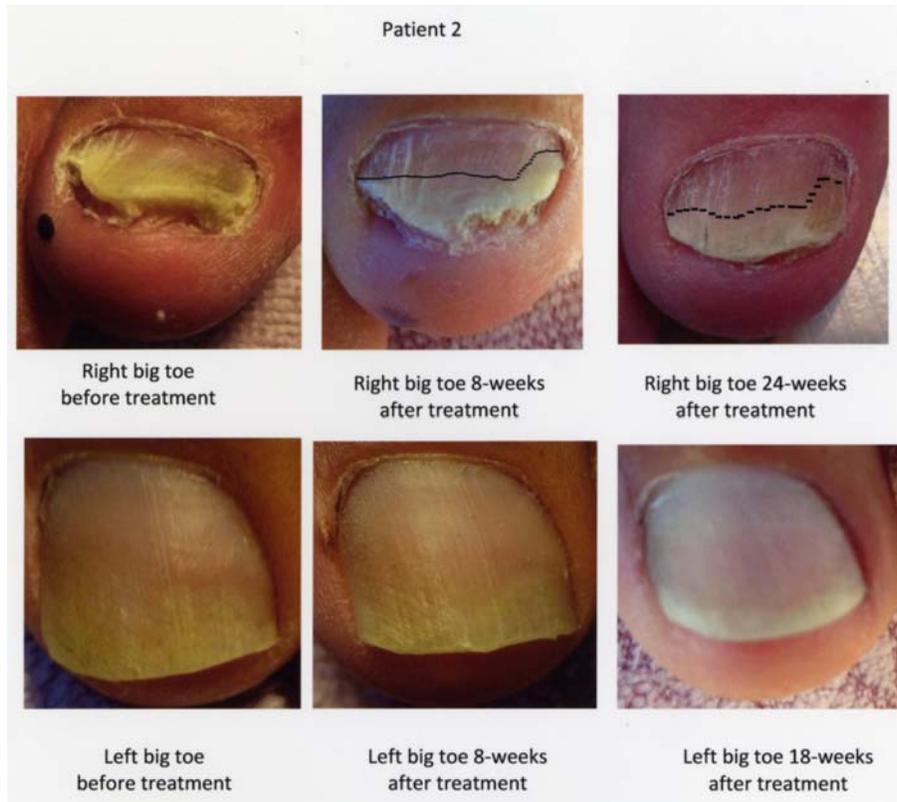


Figure 10. Patient #2 (adult male, age 58)

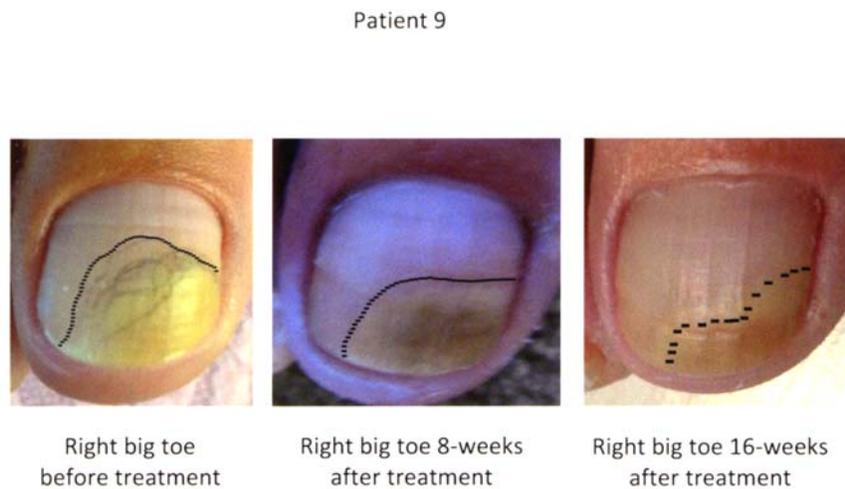


Figure 11. Patient #9 (adult female, age 56)

## 5. CONCLUSION

We examined the effects of 1534nm laser treatment on Onychomycosis fungal infections of the toenail. A simple and efficient procedure was developed that proved to be an effective method of killing toenail fungus with little to no patient discomfort. Low power density laser pulses (~ 100mj, 3ms) were employed in a matrix pattern covering the nail surface. Spectroscopic evidence suggests that the 1534nm laser emission wavelength is well suited for this application due to its deep depth of penetration into the nail and nail bed tissues. In addition, the fungus shows a relatively high absorption at the 1534nm “eye-safe” laser wavelength. Many antifungal drugs are associated with numerous serious side-effects and dangerous drug interactions. The laser treatment appears to provide a safe and effective alternative method to conventional antifungal medications.

## REFERENCES

- [1] D. De Berker, “Fungal nail disease.” *New England Journal of Medicine*, 360(20): 2108–2116. (2009)
- [2] U.S. Food and Drug Administration, FDA issues health advisory regarding the safety of Sporanox products and Lamisil tablets to treat fungal nail infections. FDA Talk Paper T01-22 (2001)
- [3] J. Ferrari, “Fungal toenail infections,” Online version of BMJ Clinical Evidence, (2008)
- [4] D. Harrisa, B. McDowellc, J. Strisowerb, “Laser treatment for toenail fungus,” *Proc. of SPIE* . 7161, (2009)
- [5] S. Kozarev, “Laser treatment of nail fungal infection,” *Laser and Health Academy, EADV Berlin*, (2009)
- [6] A. Landsman, A. Robbins, P. Angelini, C. Wu, J. Cook, M. Oster and E. Bornstein, “Treatment of Mild, Moderate, and Severe Onychomycosis Using 870- and 930-nm Light Exposure,” *Journal of the American Podiatric Medical Association*, 100, pp.166-177, ( 2010).
- [7] J. Kozarev, Z. Vižintin, “Novel Laser Therapy in Treatment of Onychomycosis,” *Journal of the Laser and Health Academy Vol. 2010, No.1*, (2010).
- [8] M. Bogle, J. Dover, K. Arndt, S. Mordon, “Evaluation of the 1,540-nm Erbium:Glass Laser in the Treatment of Inflammatory Facial Acne,” *Dermatol Surg.* Jul;33(7):810-7.,(2007)
- [9] S. Angel, D. Boineau, S. Dahan, S. Mordon, “Treatment of active acne with an Er:Glass (1.54 microm) laser: a 2-year follow-up study,” *J. Cosmet Laser Ther.* Dec;8(4):171-6., (2006)
- [10] A. Turlaki, M. Galimberti, G. Pellacani, P. Bencini, “Combination of fractional erbium-glass laser and topical therapy in melasma resistant to triple-combination cream,” *J. Dermatolog Treat.* Apr. 12. (2012)
- [11]. H. Kim, T. Kim, Y. Kwon, J. Park, J. Lee, “Comparison of a 1,550 nm Erbium: glass fractional laser and a chemical reconstruction of skin scars (CROSS) method in the treatment of acne scars: a simultaneous split-face trial,” *Lasers Surg Med.* Oct;41(8):545-9., (2009)
- [12] US Food and Drug Administration, Center for Devices and Radiological Health, CDRH 1040.10 and American National Standards Institute “ANSI 136.1 MPE level standards”. (1993)
- [13] Schlefman BS, “Onychomycosis: A compendium of facts and a clinical experience,” *J Foot Ankle Surg.* 38:290–302, (1999)
- [14] Ghannoum MA, Hajjeh RA, Scher R, et al., “A large-scale North American study of fungal isolates from nails: The frequency of onychomycosis, fungal distribution and antifungal susceptibility patterns,” *J Am Acad Dermatol.* 43:641–648, (2000)
- [15] Zaias N, Glick B, Rebell G, “Diagnosing and treating onychomycosis,” *J Fam Pract.* 42:513–518, (1996)
- [16] Christian Raulin, Syrus Karsai, “Laser and IPL Technology in Dermatology and Aesthetic Medicine,” Springer, Apr 25, (2011)
- [17]. Zhao ZQ, Fairchild PW "Dependence of light transmission through human skin on incident beam diameter at different wavelengths"; *SPIE Proceedings of Laser-Tissue Interaction IX. Volume 3254*, 354-360, (1998)
- [18] Kristian P. Nielsen, Lu Zhao, Jakob J. Stamnes, Knut Stamnes, Johan Moan, “The optics of human skin: Aspects important for human health,” *Solar Radiation and Human Health*, Oslo: The Norwegian Academy of Science and Letters, (2008)
- [19] R. Simpson, J. Lauferb, M. Kohib, M. Essenpreis, M. Copeb, “Near infrared optical properties of ex-vivo human skin and sub-cutaneous tissues using reflectance and transmittance measurements,” *SPIE Optical Tomography and Spectroscopy of Tissue: Theory, Instrumentation, Model, and Human Studies II*, 307 SPIE Vol. 2979, pp. 307-312, August 18, (1997)
- [20] C. Moss, R. Ellis, W. Murray, W. Parr, “Infrared Radiation,” Chapter 3, Euro-Series, World Health Organization, Working Group on Health Implications of the Increased Use of NIR Technologies and Devices, Oct. (1985)

- [21] Kusse Sukuta Bersha, "SPECTRAL IMAGING AND ANALYSIS OF HUMAN SKIN"  
Master Thesis Report, University of Eastern Finland, June (2010)
- [22] Hardy, J.D. et al., "Spectral reflectance of human skin in the region 0.7-2.6 $\mu$ m," Journal of applied physiology, 9:257-264, (1956)
- [23] A. Bashkatov, E. Genina, V. Kochubey, V. Tuchin, "Optical properties of human skin, subcutaneous and mucous tissues in the wavelength range from 400 to 2000nm," J. Phys. D: Appl. Phys. 38, 2543–2555, (2005)
- [24] N. Berardo, V. Pisacane, P. Battilani, A. Scandolaro, A. Piteri, A. Marocco, "Rapid Detection of Kernel Rots and Mycotoxins in Maize by Near-Infrared Reflectance Spectroscopy,". Italian Ministry of Education and Ministry of Agriculture, July 28, (2005)
- [25] Wikipedia, "Infrared" (2012)
- [26] K. Peiris, M. Pumphrey, F. Cowell, "NIR absorbance characteristics of deoxynivalenol and of sound and Fusarium-damaged wheat kernels," Journal of Near Infrared Spectroscopy, 17, 213-221, (2009)
- [27] HE Shu-mei, LIU Jing-lan, "Study on tissue construction of onychomycosis by FTIR," Chinese Journal of Analysis Laboratory, #6, (2006)
- [28] Kigre, Inc., AO-1010 data sheet, (2012)
- [29] M. Myers, J. D. Myers, J. Sarracino, C. Hardy, B. Guo, S. Christian, J. A. Myers, F. Roth, A. Myers, "LIBS system with compact fiber spectrometer, head mounted spectra display and hand held eye-safe erbium glass laser gun", SPIE Photonics West 2010, Solid State Lasers XIX: Technology and Devices Conference LA101, # 7578-87, January 26, (2010)
- [30] M. Myers, J. Myers, B. Guo, C. Yang, C. Hardy, J. Myers, A. Myers, S. Christian, "Non-invasive in-situ detection of malignant skin tissue and other abnormalities using portable LIBS system with fiber spectrometer and eye-safe erbium glass laser", SPIE Photonics West, Biomedical Optics (BiOS) Conference # 6863-33, Optical Diagnostics and Sensing VIII, January (2008)
- [31] Kigre, Inc. "Transmission spectra taken on Jasco model V-670 spectrophotometer and quartz cuvette", (2012)