DESIGN, SIMULATION, AND PERFORMANCE ANALYSIS OF PIGMENTATION REMOVAL BY USING LASER

Oras Ahmed Shareef
College of Electrical and Electronic Technique, Iraq- Baghdad

E-Mail: Oras_laser_79@yahoo.com

ABSTRUCT:

The paper describes the design and performance analysis of pigmentation removal using a Q-switched lasers (Nd:YAG 1064nm and frequency doubling source of 532 nm) at fluence(2-12.7J/cm^2) used to remove (black, blue, and green) and (red) pigment respectively, for different skin types(I-IV). All parameters calculated and selected by using a model for a laser system simulated and practically(clinically) by using IPL Q-switched laser source depending on skin color and tattoo specifications to satisfy the number of lesions.

Visual observation and histological analysis of biopsies performed to evaluate the results of relation among spot sizes, laser intensity and skin parameters for several treatments. The behavior of the Nd:YAG 1.064 nm was the safer to use clinically in real cases to get minimal adverse reactions and complications .

KEYWORDS: Pigmentation, Tattoo Removal, Q-Switched laser ,Nd:YAG laser, KTP

تحليل تصميم ، محاكاة ، و تنفيذ عملية ازالة التصبغات الجلدية باستخدام الليزر

الملخص :

هذا البحث يصف تصميم وتنفيذ تحليلي لازالة التصبغات الجلدية الموجودة في جلد الانسان باستخدام ليزرات نبضية (نيديوم : ياك بطول موجي 1064 نانومتر لازالة التصبغات بالالوان(الاسود والازرق والاخضر) وبشدة (2-12.7 J/cm^2) و مصدر مضاعفة التردد بطول موجي 532 نانومتر لازالة التصبغات باللون الاحمر لمختلف انواع الجلد (التصنيفات القياسية الخمسة لانواع البشرة). كل العوامل المؤثرة قد تم حسابها واختيارها باستخدام موديل محاكاة لمنظومة الليزر بشكل برمجي وعملي (سريريا) بالتحكم بشدة المصدر النبضي واعتمادا على مواصفات الجلد مثل اللون ومواصفات الصبغة (عمقها ونوعها ولونها) لتحديد عدد الجلسات اللازمة لاكمال ازالة التصبغ بشكل نهائي .

الفحص المرئي والتحليل المنطقي تم تسجيله بتغير حجم البقعة لليزر وشدة الليزر ومواصفات الجلد لعدة جلسات باوقات قياسية .سلوك ليزر النيديوم:ياك بالطول الموجي 1064نانومتر كان الافضل باعتباره الامن في التخلص من التصبغات باقل عدد من الجلسات ودون التاثير على الخلايا المجاورة وبدون ترك اي مضاعفات من حروق او جروح.

1. INTRODUCTION

Dermatological application of lasers are based on properties of skin and on histological investigations of the laser effect on normal and abnormal tissue [1, 2].

The choice of lasers and exposure parameters must be based on an understanding of the physical mechanisms of laser-tattoo interactions, the optical and thermal properties of the tissue, or rational, theoretical approach to maximize therapeutic benefits and minimize adverse reaction and complication such as scarring , hypopigmentation, hyperpigmentation, partial removal, infection, bleeding and tattoo ink darkening [2].

1.1 .MECHANISM OF TATTO REMOVAL

The mechanisms of Q-switched laser tattoo removal (fluence 2-12.7 J/cm^2) result from selective photothermolysis and thermokinetic selectivity. Ink dye (tattoo) allowing for selective targeting of pigment while sparing the surrounding normal tissue skin. As the laser transfers energy to the application site, the surrounding epidermis has time to cool while the pigment is heated and broken into smaller pieces as shown in figure (1) [3].

The uses of imiquimod in conjunction with the laser increase the efficiency of the removal by stimulating the immune system after the laser treatment. At that time, macrophages should be stimulated to engulf the tattoo ink by endocytosis [3, 4].

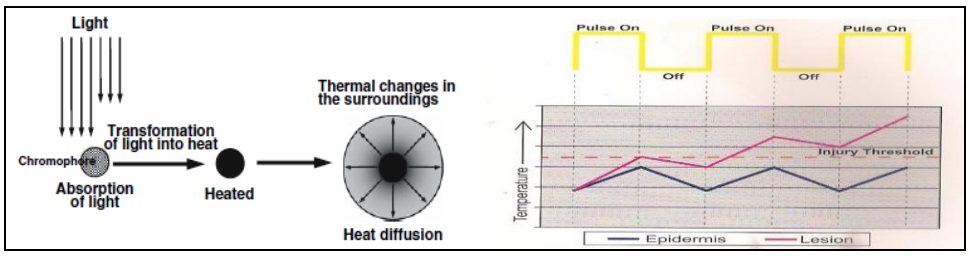


Figure 1: The Changes of A chromophore After Laser Irradiation Supplied on Skin Tissues [3]

2.RELATED ELEMENTS

Several parameters are used to provide a good assessment of the anticipated number of treatments required to achieve complete tattoo removal.

2.1 Choice of Laser

The laser must be chosen according to the ink penetration and color, after that the parameters of the chosen laser must be adjusted according to the skin specifications and the type of ink as shown in figure (2) [2] .

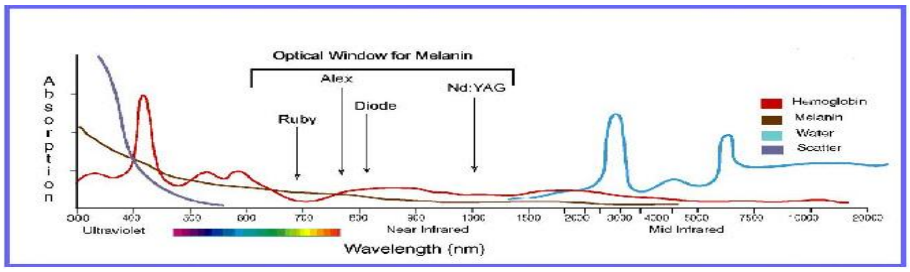


Figure 2: Multiple Sequential Pulsing using a Broad Spectrum of Light According to Skin Layer Absorption [2]

As with any type of laser ,when its supply is on target, it will cause a heat flow from the target to its surroundings causing a thermal denaturation and coagulation of adjacent structures, which may cause excessive scarring and delay wound healing as shown in figure (3) .To avoid this problem especially in the medical applications of the laser on skin must be safe , a selective photothermolysis concept must be applied where heat must be confined largely to the target by using pulsed lasers ,the pulse duration of which is briefer than the thermal relaxation time (TRT) of the chromophore-bearing target structures [2,5].

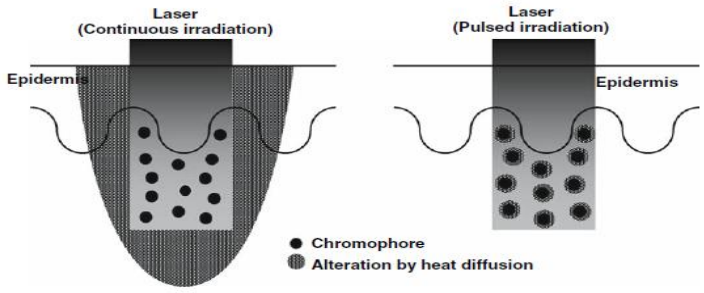


Figure 3: Difference Between Conventional Laser Therapies using Laser Continuous Beam and Laser Pulse Beam [2].

A Q-Switched laser is a destruction of subcellular structures because of its specifications, the wavelength that is strongly absorbed by the targeted organelle caused penetrates into the pigmentations [2, 6]. The threshold exposure dose for selective damage of melanosomes is wavelength-dependent in a manner grossly consistent with the absorption spectra of melanin that is mean, greater exposure is required at longer wavelengths[2, 7].As well as, a pulse duration (pulse width) of it is short enough to confine the thermal energy within the target .And finally , a pulse intensity of it sufficient to heat the organelle above some threshold temperature.

The Nd:YAG Laser (1,064-nm) can be passed through an optical crystal (KTP) that doubles the frequency and halves the wavelengths to yield green light with a wavelength of 532 nm.

Besides being useful in the removal of red, orange, and purple-colored tattoos, the Q-switched 532-nm Nd:YAG laser has been found to be a safe and effective method of treatment for red ink tattoo reactions in combination with topical Dermovate [8].

From the fundamentals of circulating power [9],the circulating power density(I_{circ}) is

$I_{circ}=(I_L+I_R) / 2$ ……(1)

$I_{out}= (1-R_1)I_L$ ..……(2)

And $I_R=R_1 .I_L$ ……(3)

Where I_L and I_R are the intracavity one way intensities of the left and right traveling resonator beams .

By the approximation ($I=I_L+I_R$) equation (3) become

$P_{out}= AI \left(\frac{1-R}{1+R}\right)$ ……(4)

Where R is the reflectivity of the output mirror, A is the cross section area of the gain medium, and I is the total power density in the resonator.

For values of R close to one (hight reflectivity) ,equation(4) reduces to :

$P_{out}= AIT/2$ …….(5)

Where T is the transmission of the output mirror.

The total efficiency of the system used in Q-switched laser (the amount of absorption tissues for laser)

$\eta_a = P_a/P_e$ ……(6)

Where P_a is the total power absorbed by the tissue, and P_e is the total power emitted by the laser source.

2.2 Skin Type

According to Fitzpatrick scale , the skin types classified into six classes based on the reaction to ultraviolet radiation, denoting the degree of skin pigmentation and thus melanin deposition. Melanin tattoo ink is a light-absorbing compound of similar size. Therefore, melanin and tattoo pigments share similar thermal relaxation times; the time needed to dissipate heat absorbed during laser-pulse administration figure(1) , which relates to the energy level needed to disrupt the granules of both melanin and tattoo pigment[10, 11].

2.3 Tattoo Colors

Two types of tattoo (amateur and professional tattoos) differ in their physical and chemical composition of ink. Amateur tattoos tend to use l carbon particles while professional artists use organic dyes mixed with metallic elements and have a propensity to mix pigments to achieve a desired color [12, 13].Also the difference in amount of treatments depend on the differences in pigment size and composition [11, 13].

According to Kirby-Desia score [11] the Black pigments are the easiest to remove due to the lack of metallic elements, and ability to absorb every wavelength of light. Red pigments that contained from mixture of metallic and carbon elements with a smaller percentage of titanium dioxide, are also considered easily removable in comparison to other colors, such as green and yellow [11, 14] . Other colors, such as green, yellow, and orange are more difficult to remove and warrant a higher amount of points on the Kirby-Desai scale**.**

2.4 Amount of Ink

Amount of tattoo or type of tattoo (The professional or amateur) is another parameter that affects on laser tattoo removal. Amateur tattoos are usually placed unevenly in the superficial dermis and tend to contain less ink than professional artists. amateur tattoos tend to respond quicker to laser treatment than the professional tattoos because it lie deeper in the dermis and have a greater density of pigment [15, 16].

2.5 Number of Sessions

To complete laser tattoo removal, multiple treatment sessions was needed, typically spaced at several weeks depending on the area of the body treated and skin color.

At each session, some but not all of the tattoo pigment particles are effectively fragmented, and the body removes the smallest fragments over the course of several weeks to became lightened over time. Large particles of tattoo pigment are then targeted at subsequent treatment sessions, causing further lightening [11].

3. CLINICAL EXPERIMENT AND RESULTS

Clinical results obtained from IPL QUANTUM Nd:YAG laser 1064nm device .

Lasers with a shorter pulses have a safer and more efficient removal method because the peak power of the pulse is greater [2]. In this work Pulse duration (time duration) taken (6-8 ns).

Due to optically scattered of light in skin, larger spot sizes slightly was increased the effective penetration depth of the laser light, thus enabling more effective targeting of deeper tattoo pigments. Larger spot sizes also help make treatments faster. Multi Spot size(width of the laser beam) (2,2.5,3.5,5 mm diameter) taken depending on skin type & specifications of ink such as old, penetration, color, type .

Fluence(J/cm2) or energy level is important to get treated at high enough settings to fragment tattoo particles, the fluence rang used (2-12J/cm2).

Finally, repetition rate also helps make treatments faster, but is not associated with any treatment effect .In our work, the repetition rate in the used device was up to 5 Hz.

Table (1) shown the major parameters explained for laser skin, ink to get high efficiency for tattoo removal in a less number of lesions.

Table 1: Clinical Result for Different Skin Type

Skin type	Skin color	Spot Size (mm)	Fluence (J/cm^2)	Number of lesions
I	White, very fair, red or blond hair, blue eyes, freckles	2	12	3-5
II	White, fair, red or blond hair, blue, hazel, or green eyes	2	12	4-6
III	White or olive skin tone, fair with any eye or hair color	2.5	8	4-6
IV	Brown	3	4	4-6
V	Dark Brown	5	4.2	4-7
VI	Black	5	4.2	4-8

In Iraq , the common Fitzpatrick skin type is (IV) which is brawn , need $4J/cm^2$ to remove the pigment by take spot size equal 3mm, this parameter was safety from any side effects like scarring , bleeding…, and others.

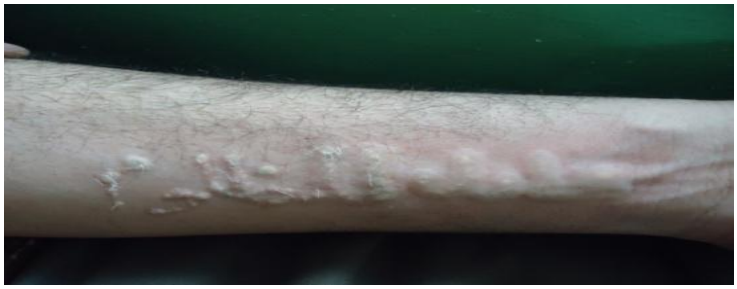
Figure (4) , real photographs represented a good example for the common skin , ink type case (IV type ,with tattoo tend to Blue color) with two parts and different times .

The first word (in the left) with bold letters (large amount of ink) ,made from 12 years ago from the date of lesion and the second word (in the right) , fine letters (little amount of ink),made after this time in 15 years ago from the same time of lesion .That is mean two words with different age and different amount of ink each them suffered from whitening but with different response as soon as exposure to laser with the same parameters (3mm spot size and fluence $4J/cm^2$) .

Photons of Nd:YAG laser penetrated the molecules of tattoo, which try to absorb the energy, but adequately fail to break the bonds of the pigment molecules reducing them to smaller sized molecules. Then the macrophages absorb the smaller molecules and return them to the lymphatic circulation .

The whitening phenomenon which represented the best response caused tattoo lightening . Figure(4-b) appeared the response of the first word was less than the second due to the tattoo age and amount of ink therefore it was very important to change the laser parameters according to the case. this whitening was continue about 2-4 hours, then the ink particles tried to grouping again ,therefore the second lesion was limited after 4-6 weeks to give a second lesion.

a:Before Treatment



b: After Treatment

Figure 4: Before and After Clinical Visible treatment(clinically) by Nd:YAG Laser 1.064 nm for Patient Skin Type IV

From these clinical results , the physical mechanisms for laser tattoo interaction and tattoo breakup process studies from the understanding of the effective power of laser to the patient skin according to tattoo type and the divergence control of the used laser.

4.THEORITICAL EXPERMENT AND RESULTS

The spreading of a laser beam is in accord with the predictions of diffraction theory, the wave front radius of curvature after propagating a distance z

$$R(z) = z\left[1 + \left(\frac{\pi w_o^2}{\lambda z}\right)\right] \quad \text{.....(7)}$$

and

The radius of the $1/e^2$ contour after the wave has propagated a distance z,

$$w(z) = w_o\sqrt{\left[1 + \left(\frac{\lambda z}{\pi w_o^2}\right)\right]_o} \quad \text{.....(8)}$$

where z is the distance propagated from the plane ,λ is the wavelength of light, w_o is beam waist radius ,the radius of the $1/e^2$ irradiance contour at the plane, R(z)is infinite at z=0,passes through a minimum at some finite z, and rises again toward infinity as z is further increased, asymptotically approaching the value of z itself .

The beam waist is located by using the equation:

$$z_1 = \frac{L(R_2 - L)}{R_1 + R_2 - 2L} \quad \text{.....(9)}$$

and z_1+z_2 =L where L is the effective mirror spacing,R1 and R2 are the radii of curvature of the cavity mirrors, and $z_1$and $z_2$are the distances from the beam waist of mirrors 1 and 2 respectively [17].
Figure (5) represents laser propagation in 3-D according to power with increase of the circular spot variation. Red color in the center represent the high concentration from the start of propagation with small divergence to the end of process along Z. High effect only on the center (the place of pigment points) this is reason of the surrounding tissue protection from laser beam.

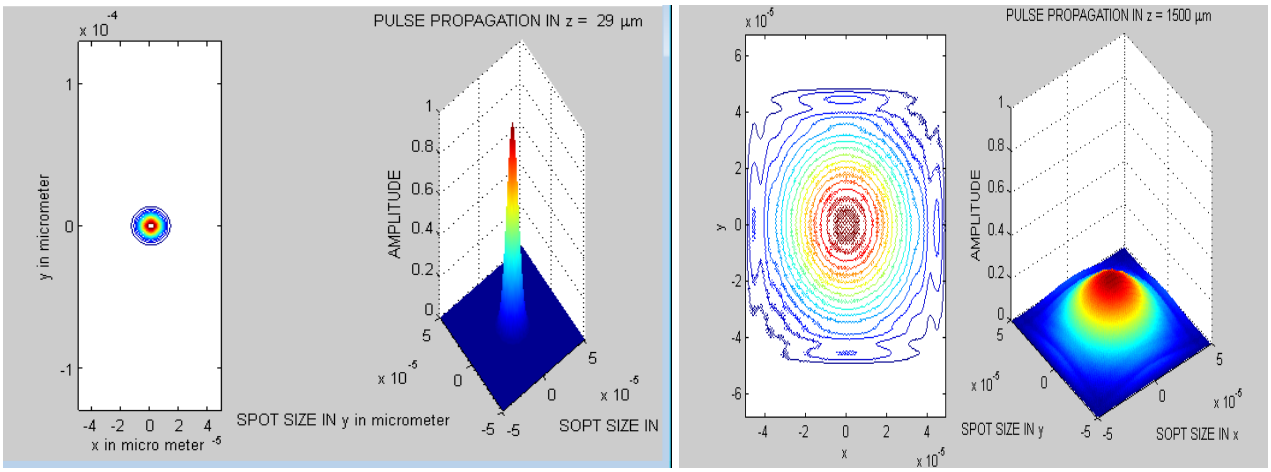
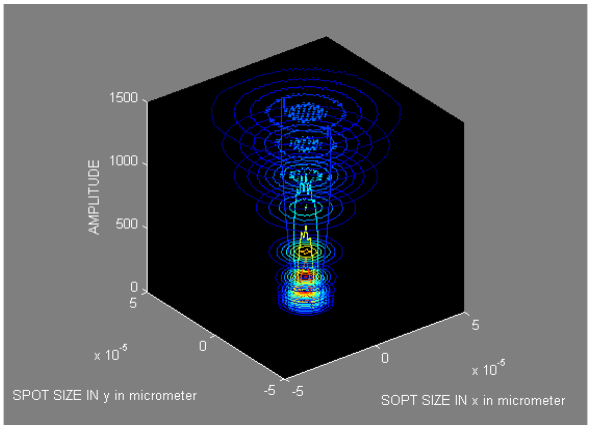


Figure 5: 3D Laser Propagation From Start to the End of Propagation Respectively

In figure (6) , 3-D simulation was presented for Nd:YAG propagation and its divergence that dealing with power and spot size variations respectively .



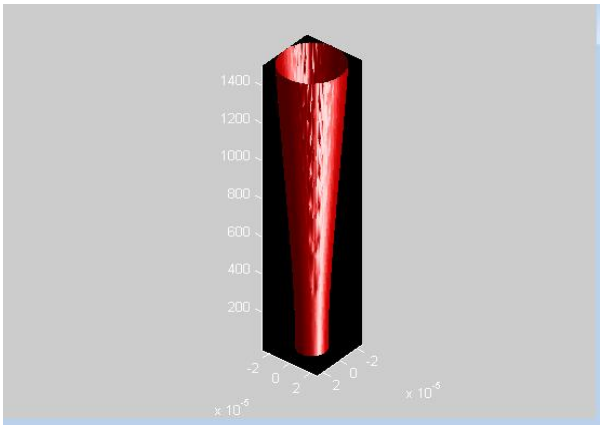


Figure 6 (a): Divergence Distribution Related to Spotsize related to power

Figure 6(b): Divergence Distribution

From the theoretical results of laser propagation from laser source to the patient skin, which used right laser source to remove tattoo. The spot size and divergence control of the laser source used to

control upon the power of laser interacted with the colored skin in 3D form to show the intensity distribution in the skin and can be determined the effective skin area after process.

5. CONCLUSION

- Q-switched Nd:YAG 1064 nm laser is the one of the successful application of the selective photothermolysis theory. It is creates a near-infrared light which is poorly absorbed by melanin; therefore it's the only laser suitable for darker skin. As well as this wavelength is also absorbed by all dark tattoo pigments and is the safest wavelength to use on the tissue due to the low melanin absorption and low hemoglobin absorption**.**

- It is important to reject the parameter of laser (spot size,fluence,pulse duration,repetation rate)according to skin specification (type, color, location) and tattoo specifications(type, penetration ,old).
- From the lesions of tattoo removal results both theoretical and practical, shows that the relatively small cone angle of laser used in this process , induced breakdown in colored skin of the patient, the pulse energy delivered inside the skin where expected according to information that recorded in table (1).
- The clinical observation appeared that the suitable period separated between each lesion was 6-8 weeks & this was match with the standard Kirby-Desai Scale .
- IPL Q-Swiched Nd:YAg 1064nm has difficult to treat with some colors such as red color. Its easy to solve this problem by placing a KTP (potassium-titanyl-phosphate) crystal inside the laser cavity itself and focusing the beam into the crystal. The result is light emitted from the crystal with twice the frequency or half the wavelength of the incident light, invisible near-IR 1064 nm wavelength light passed through the KTP crystal produces green visible light at a wavelength of 532 nm which achieves good results in the removal of red tattoo pigment with a minimal lesions. In clinical experiments these type of technique was important in mixture tattoo type which appeared as black but in fact its consisting red and other color, this is one of the reasons to maximal the treatment periods (number of lesions).

6. REFRENCES

[1] Anderson RR, Margolis RJ, Watanabe S, Flotte TJ, Hruza GJ, and Dover JS ., 1989."Selective photothermolysis of cutaneous pigm ented cells by Q-switched Nd:YAG laser pulses at 1064, 532,and 355 nm" , J Invest Dermatol, 93, 28–32.

[2] Arch Dermatol Res,2007." Basics of laser application to dermatology , Springer ,21–30.

[3] Mohamed L. , Keyvan Nouri , Voraphol Vejjabhinanta,et.al,2009." Topical imiquimod in conjunction with Nd:YAG laser for tattoo removal".

[4] Taylor CR, Anderson R, Gange W et al ,1991." Light and electron microscope analysis of tattoos treated by Q-switched ruby laser" , J Invest Dermatol 97:131,

[5] Anderson RR, Parrish JA,1983." Selective photothermolysis, precise microsurgery by

selective absorption of pulsed radiation Science" , 220:524–527.

[6] Harber LC, Bicker DR,1981." Photosensitivity diseases: principles of diagnosis and treatment. Saunders", Philadelphia, p 87..

[7] Anderson RR, Parrish JA ,1981."The optics of human skin" , J Invest Dermatol 77:13–19.

[8] Antony FC,2003. "Harland CC Red ink tattoo reactions: successful treatment with the Q-switched 532 nm Nd:YAG laser" Br J Dermatol 149(1):94–98.

[9] Walter Kewchner, 2006." Solid state laser engineering"125-126.

[10] Bernstein E.,2006." Laser treatment of tattoos, Clin Dermato24:43–55".

[11]William K. ,Albeshl D. , Tejas D., F. Kartono, Francisca K. , Geeta P. ,2009."The Kirby-Desai Scale,A Proposed Scale to Assess Tattoo-removal Treatments, V(2) No.(3)".

[12]Sweeney S.,2006."Tattoos: a review of tattoo practices and potential treatment options for removal", Curr Opin Pediatr, 19:391–395.

[13] Taylor C, Anderson R, Gange R, et al. ,1991."Light and electron microscopic analysis of tattoos treated by Q-switched ruby laser". J Invest Dermatol. ,97:131–136.

[14]Ross E, Yashar S, Michaud N, et al., 2001"Tattoo darkening and nonresponse after laser treatment: a possible role for titanium dioxide", Arch Dermatol ,137:33–37.

[15] Kuperman-Beade M, Levine V, Ashinoff R., 2001." Laser removal of tattoos", Am J Clin Dermatol, 2:21–25.

[16]Watanabe S. ,2008 ,"Basics of laser application to dermatology",Arch Dermatol Res. , 300:21–30.

[17] Internet website (www.mellesgriot.com),"Introduction to laser technology",pp.6-7.