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Predict the Laser Power and Recovery Period in Treatment by Endovenous Laser Ablation (EVLA)

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Abstract

Eight patients (3 male and 5 female) were treated in this study by Endovenous Laser Ablation (EVLA); Mathematical models are proposed to estimate the applied laser power and to assess the recovery period. The estimations of the applied laser power and recovery period in these models will be depended mainly on the diameter of the incompetent vein. In addition, Excel Program was utilized to find the proposed models. A 1470 nm diode laser up to 15W continuous power (CW) was used in the treatment of venous ulcers by EVLA procedure. Following up by duplex ultrasound was started in the 1st week after the first session until the vein is completely closed. The present study concluded that the relationship both between the applied laser power and recovery period with diameter is directly linear. The mathematical results obtained from the two mathematical proposals are consistent with the clinical results.

Keywords: 1470nm Laser, Chronic venous insufficiency, Endovenous laser ablation, EVLA, Venous ulcers.

Introduction

Using lasers has a wide and growing range of medical applications. It can be considered as the criterion of care in Ophthalmology, Otolaryngology and Dermatology[1]. Nowadays, laser therapy has become the common method in the treatment of chronic venous insufficiency (CVI) [2]. Chronic venous insufficiency is one of the most common diseases in the world affecting both men and women. This disorder has several images and degrees[3]; the last degree is the venous ulcer[4]. There are several causes related to this disease including obesity, standing for long periods, heredity and family history, vein thrombosis and etc.[5, 6]. Venous ulcer is an open wound that exists between ankle and knee[7]. This disease generally is a result of incompetence in the valves of the veins that carry blood to the heart for completing the blood circulation[8]. The healing of these ulcers was considered very difficult and sometimes required traditional surgery. Briefly, the traditional treatments include drugs, compression stockings, and surgeries[9], but due to the wide range of development in the laser's applications especially in medical applications. Laser therapy has been used in the treatment of chronic venous insufficiency (CVI). Laser treatment of this disease has been remarkably successful in treating varicose veins and venous ulcers. There are several laser wavelengths

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were used in medical applications and the treatment of venous ulcers such as 1470nm, 810nm, 940nm 980nm[10].

Treatment of venous ulcers by endovenous laser ablation (EVLA) is one of the relatively recent treatments, but it is widely spread around the world these days[11]. That is due to its actual success in closing the incompetent veins and stopping the blood reflux in these veins as well as the low pain and low recurrence rate[12]. EVLA can be considered a solution without surgical intervention in the treatment of abnormal veins caused by chronic venous insufficiency. It can be performed either with continuous wave mode or pulsed mode by different wavelengths[13].

As is well known, the success of any treatment depends on the good selection of the related parameters whether they are for the patients or for the used devices in the treatment. Appropriate selection of the related parameters leads to achieve the goals and avoid side effects. Then, the treatment of ulcers by laser has developed widely through medical centers and private clinics. This has led many researchers and scholars to develop and evaluate this treatment in order to enhance the EVLA process. [13]Developed two computational models to simulate the endovenous laser ablation process under different experimental conditions such as power, pullback speed, and vein diameter. The conclusion of this study indicated an interest in adjusting the laser power according to the diameter of the vein. Also, the diameters of the veins, applied laser power, and pullback speed has a major role in the success of EVLA because these parameters determine the thermal response. [14]Compared the beneficial effect of using laser in venous leg ulcer treatment with traditional treatment. This study demonstrated the treatment by laser was better than other treatments through wound closure and reduction of ulcer surface area. [15]Showed results of using two laser devices of different wavelengths in the treatment of defects in the great saphenous vein. The treatments were done by1470 nm EVLA and 810 nm EVLA. The advantages of the 1470-nm were economic cost and the patient surgical comfort. [16]Used the diameter of the vein to determine the applied laser power in the treatment of venous ulcers by hybrid method of EVLA. [17]Concluded that the use of 1470nm diode laser is a successful and safe method in treatment of varicose veins in the lower limbs. This conclusion came from treating of 287 patients over two years and following up on their health conditions. [18]Suggested a mathematical model for the behavior of temperature profiles in EVLA treatment. The related parameters such as wavelengths, pullback speed and power were varied in this model by numerical experiments not in the real treatments. [19]Proposed a linear and non-linear mathematical model to calculate the full cure time for venous leg ulcers depending on thermo-graphic analysis of ulcer was performed. The effect of the longer wavelength of the used laser on the amount of the generated heat in the veins was studied in[20]. Where, the study concluded that the longer wavelength is preferred to be used in thin-walled veins with low applied laser power. [21] Developed a thermo - physical model of EVLA. This model depended on the controlling of the applied laser power according to the heat of veins. In this study, the 980 nm with an average power of 8–14 W was used.

In this paper, two mathematical equations were extracted from the graphics which were obtained by studying and analyzing the practical results of the treatment by EVLA. The first equation was used to predict the amount of laser power that should be applied in the treatment. In this model, adjusting the applied laser power depended on the diameter of the vein before treatment. The second equation was used to predict the recovery period after treatment by depending on the diameter of the vein as well.

Methodology

The study included eight patients 3 male and 5 female, who have venous ulcers in their lower limbs. The cases were gathered and treated in private clinics and Al-Sadr Medical City. After the physical examination, patients undergo ultrasound imaging by Versana Essential device in order to determine the diameter of the veins, number of incompetent valves, location and length of incompetent veins. Then, patients were treated with endovenous laser ablation procedure (EVLA). A 0.6mm fiber optic probe connected to a 1470-nm diode laser (Wuhan Gigaa Optronics Technology Co., Ltd, Model: VELAS II-15D - China) was used in the treatments of the eight cases. The treatments were by continuous wave laser mode (CW) in the 5-15 W power range. This range of power depended on the related results which were determined by ultrasound imaging devices. Follow-up involved clinical examination and ultrasonography until

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complete recovery of the patient. The recovery period varied from patient to patient depending on diameter of the veins, length and location of incompetent veins, presence of blood reflux and severity of the disease.

Results and Discussion

Results

Endovenous laser ablation (EVLA) can be described as shrinking, collagen retreating, thrombosis, and fibrosis. In addition, the ablation depends on vein diameter, thickness of the vein wall, distance between the skin and vein and the pullback speed[22, 23]. In current work, the diameters of the target veins were measured by ultrasound imaging device. For the eight cases, the examinations determined the smallest diameter of them is 4.5mm and the largest diameter was 14 mm for the eighth case. The mean age of the patients was 45.125 years.

Depending on the severity of the vein damage, two pullback speeds were used 0.2 cm/s and 0.3 cm/s. In addition, in all cases, there was one treatment session except for the eighth case, which required a second treatment session after one week after the first session. The severity of the incompetent vein can be seen in the images before treatment by ultrasound imaging device. Table. 1, shows the details of cases and treatments. The duration of treatment ranged from 3 to 7 minutes. Stopping and restarting the EVLA process during treatment depended on the patient's feeling of pain and intolerance to that pain.

The success of the EVLA process can be confirmed by the ultrasound examination a week after the treatment procedure. Follow-up continued until the vein is completely closed.

Table 1. Details of the cases and their treatments.

No.	Gender and Age	Duration of treatment [mint.]	Vein Diam. [mm]	Power [W]	Spot Diam. [mm]
1	F – 45	3	4.5	5	0.6
2	M – 48	3.5	5.2	6	0.6
3	F – 35	3	6.3	7	0.6
4	M – 40	4	9	9	0.6
5	F – 50	4.5	10	11	0.6
6	F – 43	4	12	13	0.6
7	F – 45	4	13	12	0.6
8	M – 55	5 and 2	14	15	0.6

Discussion

Relationship between Power and Diameter of Vein

In the treatment of the eight cases, the applied laser power was chosen based on the experience of doctor and this power was also adjusted depending on the patient's feeling of pain. Applied laser powers set to value 5 W for the smallest diameter and 15 W for the largest diameter. Thus, Fig.1 represents the relationship between applied laser power and diameter of the treated vein before treatment.

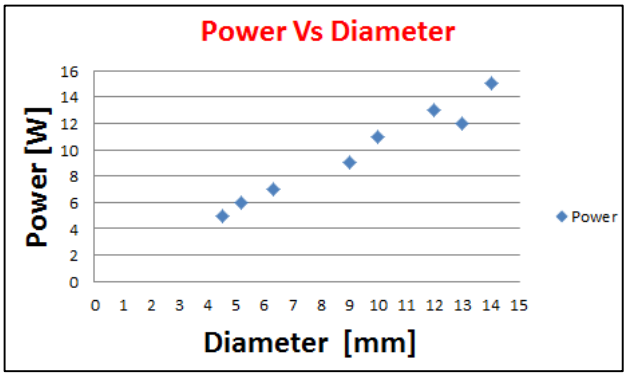

Figure 1. The relationship between power and the diameter before treatment

According to Table 1, the behavior of laser power with respect to the diameters for the treatment of the cases can be seen in Fig.1. Then, the linear model for that behavior can be deduced from this curve by Microsoft Excel program as in

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Eq. 1. This equation represents the relationship between the applied power and the diameter of vein during treatment.

$$P = 0.965\frac{w}{mm}D_{\circ} + 0.818\,w \quad \ldots\ldots\ldots 1$$

Where P is the applied laser power and $D_{\circ}$ is the diameter of incompetent vein before treatment. From Eq. 1, the slope of the linear models is 0.965W/mm. The positive sign of the slope means that the power increases with diameter of vein before treatment ($D_{\circ}$). The intercept value in the linear equations is 0.818 w represents the minimum power required. From Eq. 1, one can calculate the values of the needed power based on the diameter measurements. Table. 2, shows the comparisons of the actual values of the power at the beginning of treatment and the values according to the linear model.

Table 2. Comparisons between the actual values of the power at the beginning of treatment and the values according to the linear model.

No.	The actual power[w]	The value according to linear model [w]
1	5	5.161
2	6	5.836
3	7	6.898
4	9	9.503
5	11	10.468
6	13	12.398
7	12	13.363
8	15	14.328

The comparisons show very good approximation of the linear modeling with the actual values. Accordingly, it is possible to use Eq. 1 to estimate the applied laser power by measuring the diameter of the incompetent vein before the treatment only.

Relationship between Recovery Period and Diameter of Vein

Cases were evaluated clinically and followed up by duplex ultrasound after the first session in the 1st week until the vein is completely closed and the reflux of blood is disappeared. Fig.2 includes eight curves. These curves represent the diameter of each patient's vein during the follow-up period until complete closure. The recovery period varied in all cases due to several factors. Firstly, it is depended on the ulcer area. Secondly, it is based on the success of EVLA in complete closure for the treated vein. Thirdly, amount of blood reflux and vein diameter. Therefore, these factors have an important role in the success of the ablation. From this Fig.2, the relationship between diameter of vein and recovery period through the follow-up period was an inverse relationship. Therefore, the needed recovery period has a direct correlation with the diameter of the vein.

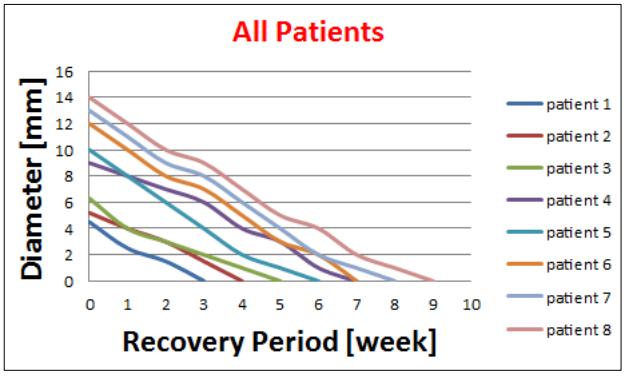

Figure 2. The diameter and Recovery Period for all patients

For each curve in the Fig.2, a linear model can be deduced by Excel program as the equations in Table 3. The linear models in this table show the behavior of laser effects on the eight different patients. From this table, the slopes of the linear models are at range of:

$$-1.185\ mm/week \geq Slope \geq -1.714\ mm/week$$

It may look as an approximate constant. So, in average the slope is$\cong -1.486\ mm/week$.

The negative sign of the slope means that the diameter is going to be reduced and the treatment is in its way of effect. The constant slope for the group of eight different patients may mean that the laser effect in such treatment cases is independent of the physical conditions of the patients, but it depends on the vein ability to accept laser effect and is going to be reduced by 1.486 mm per week for all the patients. The intercept values in the linear equations (Table. 3) depend on the patient's condition. It is the diameter of vein before treatment according to the linear model.

Table 3. The model equations of the diameter through recovery period for each case

No.	$D_{\circ}$ [mm]	The linear model[mm]
1	4.5	D =-1.450 P_r +4.300
2	5.2	D =-1.290 P_r+5.320
3	6.3	D =-1.185 P_r+5.681
4	9.0	D =-1.333 P_r+9.416
5	10	D =-1.714 P_r+ 9.571
6	12	D =-1.678 P_r +11.75
7	13	D =-1.666 P_r +12.667

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8	14	D =-1.575 P_r+13.491

According to what have been mentioned above, general linear equation is proposed for the behavior of diameter during following up as in Eq. 2:

$$D = -1.486 \frac{mm}{week} P_r + D_\circ \ldots\ldots\ldots\ldots 2$$

Where D, P_r , $D_\circ$ are the diameter at each week, time in weeks and the diameter before treatment respectively. The negative sign of the slope means that the diameter is going to be reduced and the treatment is in its way of effect. The value diameter D at full recovery period and success of EVLA will be (zero) mm. Then, Eq. 2 will be as in Eq. 3.

$$P_r = \frac{D_\circ}{1.486 \frac{mm}{week}} \quad \ldots\ldots\ldots\ldots 3$$

Eq. 3 represents the proposed linear equation for predicting the period recovery period. Thus, Table 4 shows the actual recovery period and the predicted values of recovery period according to Eq. 3 and. From the observation of the contents of Table. 4, the expected recovery periods that were required for completing the vein closure were close to the actual values in the treatments.

Table 4. The measured and calculate predicted of recovery period

No.	The measured P_r [week]	The calculate predicted P_r [week]
1	3	3.03
2	4	3.45
3	5	4.710
4	7	6.057
5	6	6.729
6	7	8.075
7	8	8.778
8	9	9.421

Conclusion

For EVLA process, two mathematical models were proposed to predict the applied laser power and recovery period depending on the diameter of the incompetent vein. The relationships of both of them with diameter were directly linear. That means for the largest diameter 14mm in this work, applied laser power was the largest in the practical side and in the mathematical model. On the practical side was 15 W while it was 14.328 W in the mathematical model. Similarly, this applied fully in case of recovery period. Thus, the results of these models were having good approximation between the actual values and the calculated values whether it was for the applied laser power or for the recovery period. Choosing the appropriate laser power speeds up the complete closure of the treated vein and stops the blood reflux, which will inevitably lead to drying of the ulcer and reduce the period of complete healing.

Author's Declaration

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been included with the necessary permission for re-publication, which is attached to the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Kufa.

Author's Contribution Statement

BGY. conceived of the presented idea. KJS. selected the cases that have been studied. BGYand SNAW verified the analytical methods. SNAW and KJ supervised the findings of this work. BGY wrote the manuscript. All authors discussed the results and contributed of the final manuscript.

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التنبؤ في قدرة الليزر وفترة الشفاء في العلاج عن طريق الاستئصال الوريدي بالليزر

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الخلاصة

في هذا البحث تم علاج ثمانية مرضى يعانون من امراض وريدية مزمنة بدرجات مختلفة (3 ذكور و 5 إناث) عن طريق استئصال الوريد بالليزر (EVLA). حيث تم استغلال نتائج العلاج لكل حالة وخصائص الحالات التي تم علاجها قبل وبعد العلاج للحصول على نماذج رياضية لتقدير قدرة الليزر الواجب تسليطها لغرض علاج الاوردة الغير كفؤة ولتخمين فترة الشفاء التام. اذ ان قدرة الليزر التي تم تطبيقها (تسليطها) كانت مختلفة من حيث المقدار والوقت بين الحالات الثمانية التي تم علاجها وكانت معتمدة بشكل تام على خبرة الطبيب المعالج. كذلك كانت فترة الشفاء التام وهي تمثل خاصية من خواص الحالات بعد العلاج معتمدة على قطر الوريد الذي تم معالجته ومدى استجابته للعلاج خلال فترة المتابعة. بعد الحصول على نتائج العلاج تم استخدام برنامج Excel للحصول على هذه النماذج المقترحة من خلال رسم العلاقة بين قدرة الليزر وقطر الوريد و ورسم العلاقة بين فترة الشفاء خلال فترة المتابعة وقطر الوريد لكل حالة ايضا . تم استخلاص المعادلات من هذه الرسومات. في هذا البحث , تم استخدام ليزر دايود 1470 نانومتر , طاقة مستمرة 15 واط في علاج الحالات الثمانية بواسطة إجراء EVLA. بدأت المتابعة بالموجات فوق الصوتية المزدوجة في الأسبوع الأول الذي كان بعد الجلسة الأولى واستمرت المتابعة الى ان تم إغلاق الوريد بالكامل لجميع الحالات. الدراسة الحالية اثبتت أن العلاقة بين كل من قدرة الليزر المسلطة و قطر الوريد والعلاقة بين فترة الشفاء و قطر الوريد هما علاقتان طرديتان. عند تطبيق النموذجين الرياضيين اللذين تم الحصول عليهما على الثمان عينات لوحظ انها تتوافق مع النتائج التجريبية (السريرية) في هذا البحث. علما ان الحالات تم جمعها من خلال عيادة خاصة ومستشفى مدينة الصدر الطبية في النجف.

الكلمات المفتاحية: ليزر1470 نانوميتر, القصور الوريدي المزمن , الاستئصال الوريدي بالليزر, القرحة الوريدية.