The relative roles of power, linear endovenous energy density, and pullback velocity in determining short-term success after endovenous laser ablation of the truncal saphenous veins

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ABSTRACT

Objective: The objective of this study was to describe the relative contributions of power output, linear endovenous energy density (LEED), and pullback rate (PBR) in determining successful long-term occlusion of the truncal saphenous veins after endovenous laser ablation (EVLA).

Methods: A consecutive 203 patients (336 ablated veins) with reflux of the great saphenous vein or small saphenous vein (Clinical, Etiology, Anatomy, and Pathophysiology class C2-C6) defined by duplex ultrasound and clinical criteria were treated with 1470-nm EVLA at a power of 6 to 12 W. Prospective outcomes were evaluated in serial clinical and duplex ultrasound follow-up. Univariate logistic regression (ULR) and multivariable logistic regression modeling assessed LEED, power output, and PBR as success predictors and optimal settings for sustained closure.

Results: Higher power outputs (8-12 W) were significantly better than lower outputs (6-7 W) for successful closure. ULR suggested a ≥90% probability of success for power output >10.34 W ($P < .001$) and LEED >26.56 J/cm ($P = .001$). Power output was foremost ($P < .001$) and LEED second ($P < .001$), and PBR was insignificant overall ($P = .38$), becoming significant only at LEED values >26 J/cm ($P < .001$). Multivariable logistic regression confirmed both power ($P < .040$) and LEED ($P < .008$) but not PBR ($P = .69$) as significant determinants. Clinical side effects were not associated by ULR with power output ($P = .14$), LEED ($P = .71$), or PBR ($P = .39$).

Conclusions: Power and LEED are separate but important determinants of short-term EVLA success. Threshold-dependent effects are observed for PBR (LEED ≤26 J/cm or ≥26 J/cm), with significant PBR correlation seen only at higher LEED values. Whereas ideal values for power and LEED differ according to the clinical scenario, our findings suggest that use of higher power outputs and greater LEED values (≥90% success probability achieved with power >10.34 W or LEED >26.56 J/cm) may yield optimal results. (J Vasc Surg: Venous and Lym Dis 2019;7:90-7.)

Keywords: Saphenous vein; Saphenous vein ablation; Saphenous vein reflux; LEED; Linear endovenous energy density

Endovenous laser ablation (EVLA) is well established in the management of lower extremity truncal venous incompetence with outcomes equivalent to if not better than those of high ligation and stripping surgery.[1-4] Multiple factors have been proposed as determinants of successful and sustained venous closure after EVLA, including total delivered energy, laser emission wavelength, pullback velocity, continuous vs pulsed mode laser emission, type of fiber tip (bare, jacketed, radial), and linear endovenous energy density (LEED).[5] LEED is an approximation for the actual linear energy fluence experienced by any vein wall segment, which is in turn dependent on many factors, including the laser power output (watts = joules/second), the treatment duration, and the rate or direction in which any given vein wall segment is exposed to thermal energy (pullback rate [PBR], beam geometry, laser fiber tip configuration).[6] Variant findings are reported for the relative contributions of power output, LEED, and pull back rate in determining successful outcomes.[7,8] We sought to determine the following: the relative importance of laser power output, LEED, and PBR in obtaining vein occlusion successfully maintained across time; the threshold LEED value for ≥90% successfully sustained long-term vein occlusion; and the optimal power setting required to achieve ≥90% success across a range of manual PBRs.

METHODS

From January 2014 to July 2016, we enrolled 203 consecutive patients (336 ablated veins) into a prospective observational registry. As a prospective registry study of prevalent practice, the study protocol was approved by the Regional Hospital Ethics Review Board and complied fully with the Declaration of Helsinki. Recruited patients exhibited reflux of the truncal great saphenous vein (GSV) or small saphenous vein (SSV) by duplex ultrasound criteria (>1 second) and venous insufficiency symptoms with clinical criteria for EVLA. Inclusion criteria

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Author conflict of interest: none.

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were presence of superficial venous reflux by duplex ultrasound scan, patent and competent deep venous system, and informed consent for endovenous ablation. Patients with prior surgery, prior ablation or sclerotherapy, active phlebitis, congenital malformations, saphenous vein aneurysms, deep venous reflux or obstruction, thrombophilia, hypercoagulable states, and need for continuous anticoagulation therapy were excluded. Other exclusion criteria included prior deep venous thrombosis, age <18 years, lack of informed consent, pregnancy, inability to ambulate, current anticoagulant therapy, sclerosant allergy, prior vein ablation, and technical failure. Tumescent anesthesia and EVLA power settings of 6 to 12 W were used per the operator's preference. Any patient with significant inflow or outflow arterial disease of the lower extremities containing a >50% stenosis (specifically defined as an elevation of a segmental peak systolic velocity of more than two times) was excluded from further analysis in our study.

Any veins opened within the first 2 weeks were considered an immediate technical failure and were excluded from further analysis. The end point for analysis (termed failure) was patency of the treated vein at any time point beyond 2 weeks after EVLA. Patency was defined by duplex ultrasound evaluation (>5-cm-length multisegmental or continuous) of the treated truncal vein at immediate postablation (≥2 weeks), 3-month, or subsequent clinical evaluations.

Duplex ultrasound scanning coincided with clinical evaluation and was performed using a GE Vivid S6 device and 4-12 MHz linear broadband transducer array (GE Healthcare, Wauwatosa, Wisc). Clinical evaluation was performed within 2 months before EVLA and repeated 1 week, 1 month, and then every 3 to 6 months after ablation as the patient's compliance allowed. Significant reflux was defined as >1 second of retrograde flow by spectral Doppler ultrasound in the superficial and deep veins and was assessed after releasing thigh or calf compression in the standing position or by Valsalva maneuver, with provocative maneuvers such as active foot dorsiflexion or plantar flexion being reserved for further confirmation. Patency and reflux in the GSV, SSV, and perforating and deep veins of both limbs were evaluated. Quality of life assessments and clinical scoring for venous insufficiency severity were obtained at initial venous duplex ultrasound assessment but not repeated serially. Regression modeling was used to analyze predictors of success, LEED threshold, and optimal power settings. There were 203 serial outpatients with chronic venous insufficiency or varicose veins symptoms (Clinical, Etiology, Anatomy, and Pathophysiology class C2-C6) in one or both legs who were studied. Preprocedure and follow-up standing and supine duplex ultrasound studies were evaluated for patency, obstruction, and reflux in the GSV, SSV, and perforating and deep veins bilaterally. A single operator (S.S.S.) performed all the procedures. The 600-μm jacket-tip (effective 905-μm diameter) laser fiber (NeverTouch [AngioDynamics, Latham, NY]) was introduced to within 2 to 3 cm of the saphenopopliteal or saphenofemoral junction. The Food and Drug Administration-approved instructions for use of this device suggest a power range of 6 to 8 W and a target LEED range of 30 to 50 J/cm. Tumescent anesthesia with 0.1% lidocaine and manual pullback were employed. An AngioDynamics VenaCure1470-nm indium phosphide diode laser at power settings of 6 to 12 W in continuous output mode was used. The operator sequentially escalated the power settings from 6 W to 12 W in increments of 1 W as the case series progressed, watching for thermal side effects. Manual PBRs were entirely operator dependent (no motorized pullback was used). PBR was approximately targeted by the operator to yield an LEED of at least 30 J/cm. This rate was subject to variation dependent on clinical necessity (eg, pullback through superficial vein segments after tumescence). Postoperatively, all patients used simple analgesia and were instructed to wear thigh-high compression hose (20-30 mm Hg) for a mandatory 3 days and then for 1 month after the procedure. All patients had a 7- to 10-day postoperative ultrasound examination and clinical review and were then observed clinically and with duplex ultrasound at 3, 6, and ≥12 months as the patient's compliance allowed and clinical need determined. Clinical inquiry for pain, bruising, paresthesia, and sensory loss was made at each postoperative review and a venous reflux questionnaire was administered. One blinded observer (V.S.) performed the outcomes analysis.

Statistical methods. We used the logistic regression model to predict the successful outcome of ELVA. In a

ARTICLE HIGHLIGHTS

- **Type of Research:** Retrospective single-center cohort study
- **Take Home Message:** In 203 patients, 336 saphenous veins were treated with endovenous laser ablation using a 1470-nm laser. Successful closure was most associated with power output ($P < .001$) than with linear endovenous energy density (LEED; $P < .001$), with pullback rate insignificant with respect to closure ($P = .38$). There was a ≥90% probability of closure at follow-up with power outputs >10.34 W ($P < .001$) and LEED >26.56 J/cm ($P = .001$). Clinical side effects were not associated with power output ($P = .14$), LEED ($P = .71$), or pullback rate ($P = .39$).
- **Recommendation:** This study suggests use of higher power outputs (>10.34 W) and greater LEED values (>26.56 J/cm) to increase successful saphenous closure rates in endovenous laser ablation.

univariate logistic regression (ULR) model, the response variable is binary (success or failure), and logarithm of the odds of success is modeled as a linear function of the predictor variable. Hence, we created a success probability plot that is a function of the predictor variable. We can also extend ULR to incorporate several predictor variables, called the multivariable logistic regression model. In addition, we used the Cox proportional hazards model to examine the hazard rate (or failure rate) of ELVA based on power settings (6-7 W vs 8-12 W).

RESULTS

There were 203 patients (59% female, 41% male) and 336 ablated veins studied; 86% were GSVs and 14% were SSVs. The mean reflux times for right GSV, right SSV, left GSV, and left SSV were 3.8, 3.6, 3.5, and 3.5 seconds, respectively. The mean, median, and range of follow-up were 73.2 days, 65.5 days, and 11 to 391 days, respectively. The number of patients available at each follow-up was 203 patients at week 1, 144 at 3 months, 96 at 6 months, and 53 at 1 year. Mean ± standard deviation GSV diameter at the saphenofemoral junction was as follows: right GSV, 5.9 ± 2.1 (2-16) mm; left GSV, 6.0 ± 2.3 (2-16) mm. Mean ± standard deviation SSV diameter at the saphenopopliteal junction was as follows: right SSV, 5.7 ± 1.54 (3.6-9) mm; left SSV, 5.5 ± 1.29 (4-7) mm.

Mean ± standard deviation for age was 65.7 ± 22.4 years; body mass index, 31.8 ± 7.8 kg/m^2; LEED, 21.6 ± 7.2 J/cm; PBR, 4.7 ± 1.4 mm/s; and power, 9.7 ± 1.9 W. Concomitant prevalence of cardiovascular risk factors was extensive: diabetes, 38.1%; hypertension, 71.1%; hyperlipidemia, 66%; chronic kidney disease, 5.1%; and coronary artery disease, 11.7%. The summary statistics are presented in Table I. The total number of study failures was 56. Of 336 EVLA procedures, 3 cases of endovenous heat-induced thrombosis class 3 or class 4 were found and treated with 1 month of anticoagulation, and follow-up duplex ultrasound confirmed resolution; no other embolic complications ensued. There were five cases of transient paresthesia, dysesthesia, or numbness in the cutaneous distribution of the GSV that resolved by the completion of study evaluation in the affected patients. Of the three documented cases of endovenous heat-induced thrombosis class 3 or class 4, two occurred in the 6 W and 8 W groups and one in the 10 W group. Of the five cases of transient dysesthesia or numbness, two occurred in the 7 W group and one each in the 10 W, 11 W, and 12 W groups. There were 10 cases of bruising still evident at the 2-week ultrasound examination appointment.

The frequency of success vs failure of ablation as a function of power, LEED, and PBR was analyzed (Fig 1). Based on the frequency distributions illustrated in Fig 1, *A*, we analyzed the relationship of power to success by stratifying the power output into two groups (6-7 W and 8-12 W). When the power is at or above 8 W, the failure rate decreases as power increases. The failure rates were 64.0% (n = 25) for 6 to 7 W and 15.8% (n = 271) for 8 to 12 W. The distribution of success to failure vs LEED was skewed rightward and increased up to 20 J/cm and then plateaued. For the pullback speed, the failure rate was 18.9%, whereas the success rate was 81.1%. Within each power group, the proportions of success (sustained occlusion) to failure (reopening of treated vessel) were significantly different (6-7 W: $P < .001$ [95% confidence interval, −0.80 to −0.20]; 8-12 W: $P < .001$ [95% confidence interval, −0.76 to −0.61]). The mean values for LEED (failure vs success group) were significantly different ($P < .001$; 95% confidence interval, −7.65 to −3.14; Fig 1, *B*). The mean values for PBR (failure vs success group) were similar ($P = .233$; 95% confidence interval, −0.23 to −0.93; Fig 1, *C*).

Kaplan-Meier analysis curves for maintained closure (success) over time for the two power groups (6-7 W vs 8-12 W) are presented in Fig 2. Cox proportional hazards modeling indicates that the 6 to 7 W group displayed a significantly decreased success rate compared with the 8 to 12 W group ($P < .001$), that is, power outputs of 8 to 12 W were significantly better at ensuring long-term closure. In Table II, we present the results from the Cox proportional hazards model. The watt group is categorical where the baseline was taken to be 6 to 7 W, and LEED and PBR are assumed to be continuous. Power (hazard ratio, 0.345; $P < .001$) and LEED (hazard ratio,

Table I. Demographics, distribution of duplex ultrasound and procedure parameters, and prevalence of vascular risk factors in the study population

Variable	Mean (SD)	Median (minimum-maximum)
Age, years	64.9 (15.4)	65.7 (26.4-115.8)
Height, inches	65.3 (4.0)	65 (53-76)
Weight, pounds	194.1 (54.8)	183 (100-460)
Body mass index, kg/m^2	31.8 (7.9)	30 (16.8-62.4)
Right GSV diameter, mm	5.9 (2.1)	6 (2-16)
Left GSV diameter, mm	6.0 (2.3)	5 (2-16)
PBR, mm/s	4.7 (1.8)	4.4 (1.5-23.2)
Power, W	9.7 (1.8)	10 (6-12)
LEED, J/cm	21.6 (7.1)	21 (1-41)
Variable	**No. (%)**	**No. (%)**
Sex	Female, 119 (58.6)	Male, 84 (41.4)
Diabetes mellitus	Yes, 75 (38.1)	No, 122 (61.9)
Hypertension	Yes, 140 (71.1)	No, 57 (28.9)
Hyperlipidemia	Yes, 130 (66.0)	No, 67 (34.0)
Renal disease	Yes, 10 (5.1)	No, 187 (94.9)
Coronary heart disease	Yes, 23 (11.7)	No, 174 (88.3)
Vein	GSV, 289 (86.0)	SSV, 47 (14.0)

GSV, Great saphenous vein; *LEED,* linear endovenous energy density; *PBR,* pullback rate; *SD,* standard deviation; *SSV,* small saphenous vein.

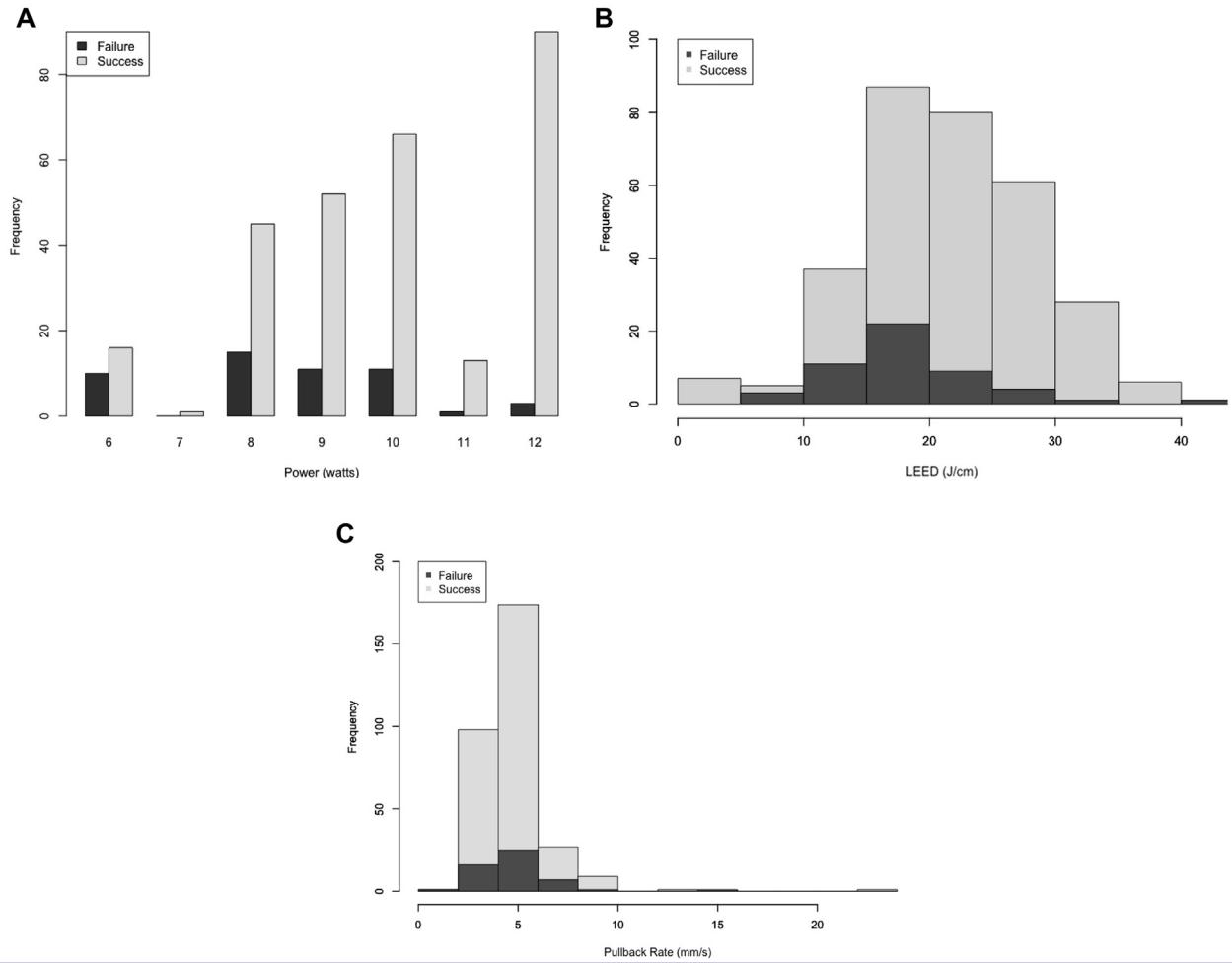

Fig 1. Frequency of success vs failure of ablation as a function of power, linear endovenous energy density (*LEED*), and pullback rate (PBR). The relationship of power to success was analyzed by stratifying the power output into two groups (6-7 W and 8-12 W). Within each power group, the proportions of success (sustained occlusion) to failure (reopening of treated vessel) were significantly different (6-7 W, $P < .001$; 8-12 W, $P < .001$). **A,** Frequency of success-failure ratios across the range of power outputs used. Greater success-failure ratios were observed at the highest power outputs between 8 and 12 W. **B,** Frequency of failure-success ratios across the range of LEED values used. The mean values for LEED (failure vs success group) were significantly different ($P < .001$; 95% confidence interval, −7.65 to −3.14). **C,** Frequency of failure-success ratios across the range of PBRs used. The mean values for PBRs (failure vs success group) were similar ($P = .233$).

0.915; $P < .001$) were significant predictors of success, whereas PBR (hazard ratio, 0.999; $P = .84$) had no overall effect on outcome.

We established cutoff values for power and LEED that yield estimates for >90% probability of success at power output ≥10.34 W ($P < .001$) and LEED ≥26.02 J/cm ($P \leq .001$; Fig 3). Using ULR (Table III), the power output was the most important variable in determining success ($P < .001$), and this remained true even after subdivision into two power groups (6-7 W vs 8-12 W; $P < .001$). LEED was also significant in determining EVLA success (odds ratio, 1.135; $P < .001$). PBR remained nonsignificant in predicting success overall (odds ratio, 0.986; $P = .764$), although at LEED >26.02 J/cm, success was positively related to PBR (odds ratio, 1.184; $P < .001$). Multivariable logistic regression analysis (Table III) confirmed both power (odds ratio, 1.752; $P < .001$) and LEED (odds ratio, 1.067; $P = .038$) as significant determinants of ablation success but not the PBR, which remained nonsignificant (odds ratio, 0.968; $P = .629$).

Ablation success was examined as a function of PBR above and below the LEED threshold value for 90% success (26.02 J/cm). The PBR at LEED <26.02 J/cm ($P = .59$) was not significant, but at LEED ≥26.02 J/cm, it was significant ($P < .001$). However, the power was significant both above and below the LEED threshold of 26.02 J/cm ($P < .001$ and $P < .001$, respectively). Incidence of side effects for up to 1 month after ablation was not significantly associated by ULR with power output ($P = .14$), LEED ($P = .71$), or PBR ($P = .39$).

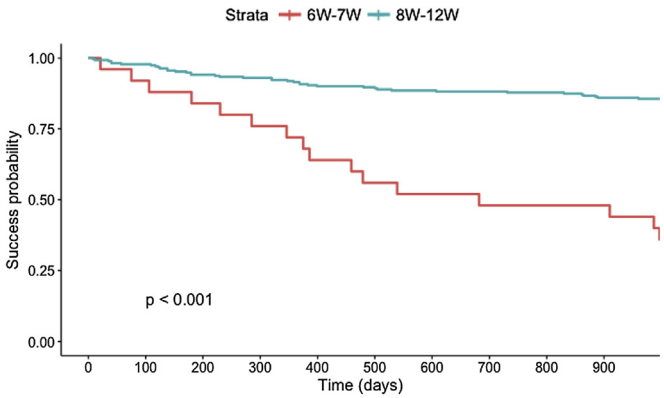

Fig 2. Kaplan-Meier analysis curves for maintained closure (success) over time for the two power groups (6-7 W vs 8-12 W). Cox proportional hazards modeling indicates that the 6 to 7 W group displayed a significantly decreased success rate compared with the 8 to 12 W group (estimate, −1.125; $P < .001$).

DISCUSSION

Power output and LEED were significant independent determinants of long-term EVLA in this study. Laser power output was the foremost determinant of success, followed by LEED. The ≥90% probability of long-term ablation success was achieved using power outputs >10.34 W and LEED >26.56 J/cm. The term LEED was introduced by Proebstle et al[9] in 2004 (total energy expended divided by treated vein length [joules/centimeter]) as a measure of the average energy delivery across the entire vein length treated. These authors demonstrated that higher energy dosing resulted in reduced GSV recanalization.[10] Given the wide variety of wavelengths, power settings, type of energy delivered (continuous vs pulse wave),[11] and tip designs (bare, jacketed, tulip, radial),[12] it is difficult to generalize regarding optimal LEED settings. A comprehensive meta-analysis by Cowpland et al[7] suggested an optimal consensus LEED to obtain best closure rates with least side effects at >80 J/cm and <100 J/cm. LEED <60 J/cm has reduced efficacy regardless of wavelength, with longer wavelengths or radial-tip fibers achieving successful closure at lower LEED values.[12-21] Using a 1470-nm bare-tip diode laser at 8 to 12 W, Park et al[22] showed sustained occlusion rates of >98% at 3 months and 1 year at LEED values of 80 J/cm or lower. We find, using a pulse wave 1470-nm laser with jacketed tip, that a 90% or greater success rates is achievable at LEED values >27 J/cm.

Table II. Cox proportional hazards model

	Hazard ratio	*P* value	95% Confidence interval
Watt group (reference group, 6-7 W)	0.345	<.001	0.148-0.541
LEED	0.915	<.001	0.869-0.961
PBR	0.999	.840	0.797-1.203

LEED, Linear endovenous energy density; *PBR,* pullback rate.

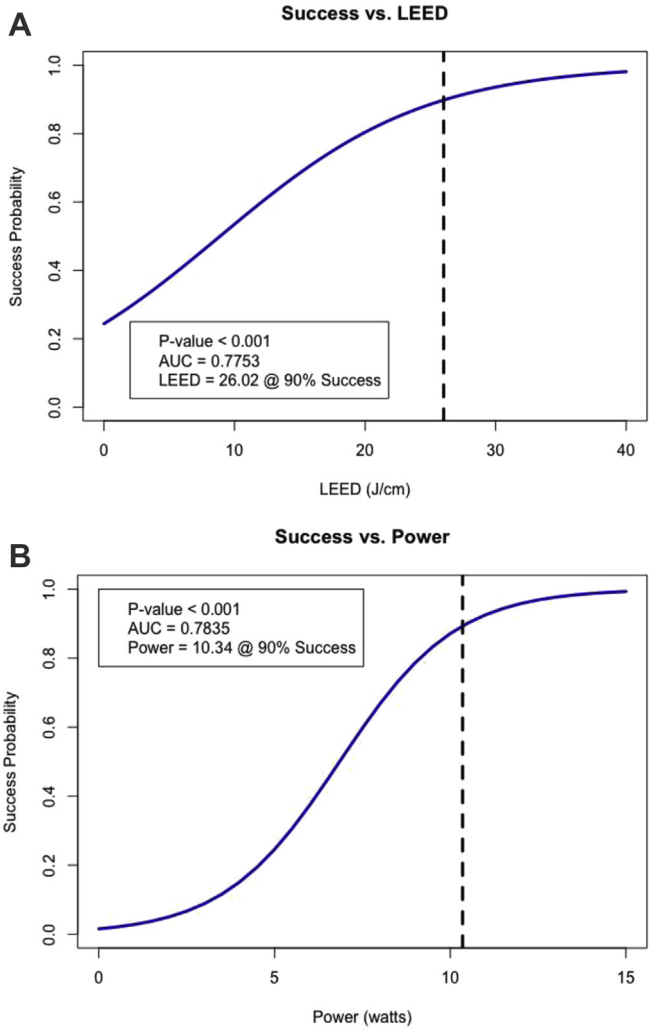

Fig 3. A and **B,** Success probability plots based on univariate logistic regression (ULR) models. We established cutoff values for power and linear endovenous energy density (*LEED*) that yield estimates for >90% probability of success at power output ≥10.34 W (estimate, 0.438; $P < .001$) and LEED ≥26.02 J/cm (estimate, 0.077; $P < .001$). *AUC,* Area under the curve.

Pullback velocity had an insignificant overall effect on long-term success, except at LEED values >26 J/cm, when pullback velocity and successful occlusion were positively related. Once LEED threshold required for ≥90% probability success (26.02 J/cm) was exceeded, there was a significant positive relationship between success and PBR. Our results suggest that at power settings that achieve LEED values below a 26.02 J/cm threshold, no variation in PBR can achieve the necessary heating effect or vein wall temperature required for satisfactory closure. However, once LEED exceeds 26 J/cm, PBRs influence results, with faster PBRs at higher power

Table III. Univariate and multivariate regression modeling analysis

	Odds ratio	*P* value	95% Confidence interval
Multivariable logistic regression models			
Intercept		<.001[a]	
LEED	1.067	.038[b]	1.003-1.136
Watt	1.752	<.001[a]	1.409-2.179
PBR	0.968	.629	0.848-1.105
Intercept		.032[b]	
LEED	1.110	.002[a]	1.040-1.184
Watt group	7.765	<.001[a]	2.703-22.306
PBR	0.960	.770	0.730-1.262
ULR models			
Intercept		.0353[b]	
LEED	1.135	<.001[a]	1.078-1.195
Intercept		.123	
Watt group	11.479	<.001[a]	4.780-27.567
Intercept		<.001[a]	
Watt	1.892	<.001[a]	1.559-2.297
Intercept		<.001[a]	
PBR	0.986	.764	0.901-1.079
Success vs power, LEED >26.02 J/cm			
Intercept		.536	
Watt	1.079	<.001[a]	1.044-1.115
Success vs power, LEED <26.02 J/cm			
Intercept		.948	
Watt	1.083	<.001[a]	1.052-1.115
Success vs PBR, LEED >26.02 J/cm			
Intercept		.006[a]	
Pullback rate	1.184	<.001[a]	1.107-1.266
Success vs PBR, LEED <26.02 J/cm			
Intercept		<.001[a]	
PBR	0.989	.593	0.949-1.030

LEED, Linear endovenous energy density; *PBR,* pullback rate; *ULR,* univariate logistic regression.
[a] *P* value significant at <.001.
[b] *P* = NS.

settings achieving the best closure rates. This is in keeping with the ex vivo experimental findings of Ignatieva et al,[23] who documented a faster rise in vein wall temperature during laser irradiation at higher power and faster pullback velocities. Thus, for any given LEED, a higher power setting at a faster PBR may achieve a higher and faster rise in vein wall temperature, improving the chances for successful vein wall closure. Most operators employ manual PBRs quoted in the literature between 0.5 and 1 mm/s. Experienced operators deliberately slow their pullback through dilated segments while increasing PBR through very superficial vein segments. A more consistently achievable manual PBR is in the range of 2 to 4 mm/s, as skilled motor functions are best achieved at moderate speeds, neither too fast nor too slow.[24]

Controversy also exists concerning the role of power output in determining outcome. Nejm et al[25] used a 1470-nm laser and a 600-μm bare-tip fiber and randomized a total of 36 patients (60 limbs), comparing outcomes between 7 W and 15 W power settings. No difference could be found between the 7 W and 15 W groups either for occlusion rates or for procedural complications at 3, 6, or 12 months. The authors stated that a constant manual pullback velocity of 0.5 mm/s was used. However, using the median treated vein lengths and the mean LEED values cited for the 7 W and 15 W groups yields PBR estimates of 2 mm/s and 1.7 mm/s for the 7 W and 15 W groups, respectively. These discrepancies and small randomized numbers make meaningful conclusions difficult. Maurins et al[26] used a 1470-nm bare-tip laser and randomized 40 patients to 15 W or 25 W power output. Because of discrepantly higher LEED values in the 25 W group, four patients with high LEED values were removed to create equivalent LEED comparisons. The 30-day outcome with 100% sustained occlusion was reported as equivalent in both groups. Selection bias with potential disparity in treatment allocation, small sample size, and variation in manual PBRs all confound accurate conclusions.

Irreversible thermal injury to the vein wall represents the final common mechanism by which EVLA achieves closure.[27,28] Emitted laser light is both scattered and absorbed by blood and vein wall constituents, resulting in heating. Heating of blood, vein wall, and perivenous tissues occurs by direct absorption of laser energy, by scattering toward the vein wall, and by diffusion of heat toward the wall.[21,28-31] Direct blood absorption of laser energy generates steam bubbles that travel downstream from the tip, promoting convective heat transfer to surrounding tissues. A hot black layer of carbonized blood may also form on the fiber tip during laser emission.[28,32] The heat stored within the carbonized blood transfers to the vein wall by direct contact, heat diffusion, and steam bubbles that condense near the wall[27] and from Planck's black body radiation (minor contribution).

LEED is expressed in joules/centimeter, which is equivalent to [watts/(centimeter/second)] because watts = joules/second:

$$\frac{\text{Watt}}{\text{cm/s}} = \frac{\text{Watt}\cdot\text{s}}{\text{cm}} = \frac{\text{Joule}}{\text{cm}}$$

LEED is represented by the ratio of laser power (watts) and pullback velocity (centimeters/second). It is different from the fluence of laser energy, which denotes the total photon energy entering an infinitesimal spherical volume of tissue divided by the sphere's cross-sectional area.[21] Discussion of outcomes based on LEED values alone, without accounting for power and PBR effects, results in only partial representation of what determines

Table IV. Three theoretical scenarios of endovenous laser ablation (EVLA)

Settings	Scenario 1	Scenario 2	Scenario 3
Length treated	10 cm = 100 mm	10 cm = 100 mm	10 cm = 100 mm
Power setting, W	3	6	12
PBR, mm/s	1	2	4
Time of treatment, seconds	100	50	25
Energy, J	300	300	300
Power-velocity ratio (LEED surrogate), J/cm	30	30	30
Maximum inner vein wall temperature calculated, °C	91-91.5	95-95.5	97

LEED, Linear endovenous energy density; *PBR*, pullback rate.
In these theoretical scenarios, a fixed length of 10 cm is treated with varying power rates and PBRs, each achieving the same linear endovenous energy density (LEED) of 30 J/cm but resulting in differing inner vein wall temperatures as predicted by the optical-thermal mathematical models of Malskat et al[21] and van Ruijven et al.[28] These scenarios are used to discuss which strategy might be most effective in achieving sustained venous closure.

outcome. Mechanistically, high wattage over short exposure intervals is proposed to cause increased blood and tissue vaporization, whereas low wattage exposure for a longer time increases tissue coagulation but reduces vaporization.[16] Few studies have examined EVLA outcomes across a spectrum of different power settings and pullback velocities.

Our results find power output (watts) to be the dominant determinant of outcome over the range of LEEDs used. PBR, although insignificant overall, did show LEED threshold-dependent effects on outcome (Fig 3; Table III). Consider a scenario using 1470-nm-wavelength laser continuous energy and a 2-mm inner vein wall diameter after tumescence using the optical-thermal model.[21,28] A LEED of 30 J/cm can theoretically be achieved using settings of 3 W at 1 mm/s, 6 W at 2 mm/s, or 12 W at 4 mm/s (Table IV). Which scenario is more effective at obtaining sustained closure? The model yields temperatures of 91°C to 91.5°C, 95°C to 95.5°C, and 97°C, respectively, for these settings.[21,28] As vein wall heating is the dominant mechanism of ablation closure, this suggests that higher power outputs at faster pullback velocity (for any given LEED value) may be the better strategy. There is experimental support for this idea. Ignatieva et el,[23,33] using an ex vivo EVLA model of human varicose vein, with outputs of 2.5 to 9.5 W, 1470-nm continuous wave laser, 360-degree radial fiber, and pullback velocity of either 0.7 or 1.5 mm/s, applied LEED of 40 to 95 J/cm and showed that the rise in vein wall temperature (infrared thermal photography) was 150% slower for PBR of 0.7 mm/s than 1.5 mm/s. Importantly, the maximum vein wall temperature at any given LEED value was greater and achieved quicker when faster PBRs were used. Consistent with our study results, higher power settings and more rapid PBR resulted in the highest vein wall temperatures at the fastest rate. Manual pullback at rates of 2 to 4 mm/s coupled with higher outputs not only may achieve better long-term venous occlusion but, by decreasing laser dwell time at any vein wall location, may also decrease complications, a hypothesis that requires future randomized confirmation.

Limitations. Nonutilization of a motorized pullback device (for pullback consistency), nonrandomized power output assignment, and a single-center study with a single operator are limitations of this study with potential for introduction of selection bias. However, this study was a prospective observational study at a time (2013-2015) when there were no definitive guidelines or manufacturer's recommendations as to optimal device settings.

CONCLUSIONS

Future randomized studies should test laser and fiber combinations using differing power and motorized pullback combinations that fix the LEED at values ≥26 J/cm to confirm the exact roles of high- vs low-power output and slow vs fast pullback velocities in determining EVLA closure success.

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AUTHOR CONTRIBUTIONS

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