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Standardisation of Parameters during Endovenous Laser Therapy of Truncal Varicose Veins - Experimental Ex-vivo Study

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Background. *Vein shrinkage is a surrogate marker for successful laser treatment of varicose veins. However, many controversies still remain concerning the best laser parameters to use. The aim of this study was standardisation of intraoperative energy dosages and pull-back rates to achieve optimal clinical results.*
Design. *Ex-vivo study in surgically removed saphenous trunks.*
Material and methods. *Great saphenous veins were removed by Babcock stripping and irradiated with laser energy delivered by a laser diode emitting at 980 nm. In total, 279 vein segments (5 cm long) were treated using powers from 5–15 W. Vein segments were opened longitudinally and the circumference measured in the treated and untreated regions to assess thermal shrinkage.*
Results. *The greatest shrinkage and minimum number of perforations was achieved using lower or medium power (8 to 12 W) with longer exposure to administer laser energy. The median percentage vein shrinkage was 50% (power 5 W), 45% (8 W), 40% (10 W), 45% (12 W) and 59% (15 W). When a higher power was used (15 W), the perforations were more frequent and carbonisation was marked.*
Conclusions. *Our data suggests that similar efficacy with fewer vein perforations may be obtained with low or medium power settings and increased exposure when undertaking laser obliteration of saphenous trunks. This may result in fewer adverse events such as ecchymosis following treatment in patients.*

Keywords: Endovenous laser; Collagen shrinkage; Power; Pull-back; Laser energy; Perforations.

Introduction

Endovenous thermal ablation procedures (radiofrequency and endovenous laser) have become popular in the management of venous disease. The aim of these methods is to destroy the vein wall by direct thermal injury. This results in immediate contraction of the vessel with subsequent occlusion and fibrosis.

Vein shrinkage is an early marker of the effects of endovenous laser treatment of varicose veins. However, uncertainty still remains concerning the best treatment parameters to use and there is only limited data from experimental and mathematical evaluation of these methods.[1–6] According to some clinical studies,[7–10] higher energy doses improve the saphenous vein obliteration rate but no standardized energy delivery protocol has been published. The aim of this study is to assist in selecting the optimum energy delivery pattern to achieve the best clinical outcome.

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Materials and Methods

Incompetent trunks of great saphenous veins (GSV) removed during saphenous vein stripping operations using a Babcock stripper under general or spinal anaesthesia were transported to the laboratory in a saline bath at 4 °C to 10 °C. The veins were cut in pieces 6 cm in length and each piece was clamped with mosquito forceps at the proximal end leaving about 1 cm of the vein beyond the clamp to protect this part from thermal injury (Fig. 1). A bare tipped laser fibre 600 microns in diameter was inserted from the distal end. Before each experiment, the fibre tip was freshly cleaved to avoid secondary carbonisation effects . The whole experimental setup was placed under an extractor hood to avoid remove potentially toxic pyrolysis products and smoke from entering the laboratory.

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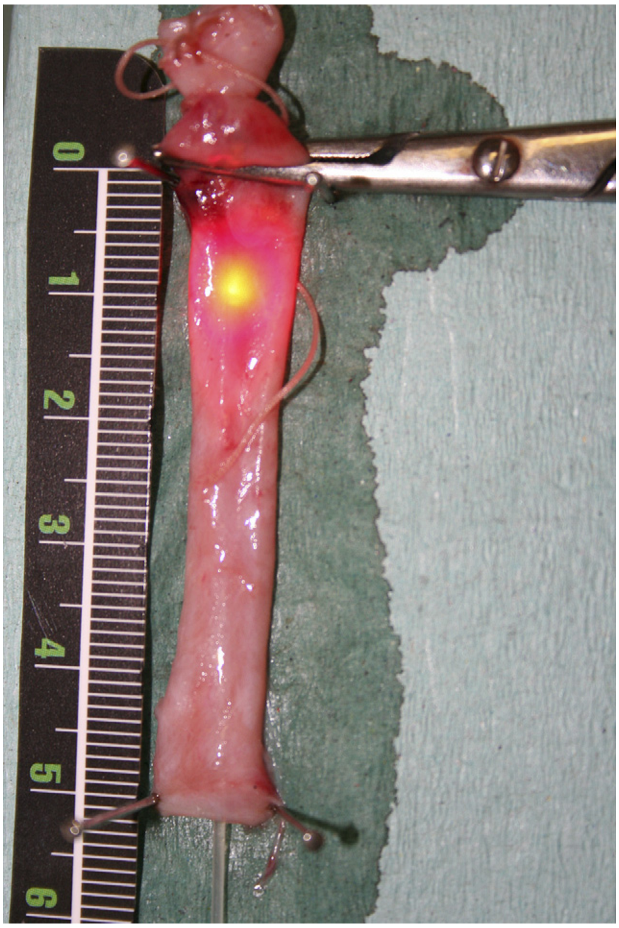

Fig. 1. Experimental ex vivo model: incompetent segments of great saphenous vein (6 cm long) removed at surgery were irradiated using 980 nm diode laser energy in the laboratory.

Fig. 2. Shrinkage of the vein following application of laser energy.

In all, 279 vein segments (5 cm long) were irradiated with laser energy delivered continuously by the diode generator emitting 980 nm laser beam (BIOLITEC, CeramOptec GmbH, Bonn, Germany). The primary endpoint of our investigation was to achieve maximal shrinkage of the vein (Fig. 2), the secondary goal was to minimise transmural injuries of the venous wall. Under direct visual inspection, we used the powers of 5 W, 8 W, 10 W, 12 W and 15 W during the longest time period possible to achieve maximum shrinkage of the saphenous veins with a minimum of perforations. The veins were irrigated with normal saline solution during laser irradiation.

The study cohort consisted of two groups - in the first group the veins were filled with heparinised blood ($n = 139$), in the other one the veins were empty ($n = 140$) to simulate the effect of limb elevation on the operating table, the impact of tumescent anaesthesia and localised pressure during clinical treatment.

After the procedure, every vein segment was divided into a treated (5 cm) and not treated (1 cm) control section, cut longitudinally and unfolded. The inner circumference of treated vein was measured and compared to inner circumference of untreated section of the same venous segment.

The perforations were the secondary endpoint of this study and were not studied systematically. In those cases in which perforations were investigated ($n = 192$) the presence and non-presence of this entity was compared to applied energy and power.

Institutional review board (ethics committee) approval was obtained for this study.

Statistical analysis

Descriptive measures were used for analysis. Results are expressed in terms of median values with ranges. Shrinkage, energy per centimetre of vein length, as well as pull- back rate of laser fibre, respectively were analysed using a Kruskal-Wallis one way analysis of variance with post-hoc multiple comparisons (Bonferroni test). To compare two cohorts (with blood vs without blood) two-sample t-test, nonparametric Mann-Whitney test or Kolmogorov-Smirnov test were used. The Fisher's exact test and correlation coefficient (Spearman) were also used when appropriate. *P* value of .05 was considered significant.

All analyses were performed using Number Crunching System Software (NCSS 2004, Salt Lake City, USA).

Results

The circumference of treated vein segments was compared to the original circumference of non-treated vein (defined as 100%) and so lower median values represents better shrinkage and vice versa. Results for powers of 8 W, 10 W and 12 W are comparable and are significantly better than for power of 15 W ($p < 0.001$) - Fig. 3. Comparing energy per centimetre of vein length, similar total doses were used in all groups. There was no significant difference between the blood filled veins and the empty veins (Fig. 4). As would be expected, the pull-back speed of the laser fibre during the procedure was lower in the lower power groups than the higher power groups (Fig. 5). In summary, the results of both cohorts (with and without blood) show that although the pull-back speed is slower in the lower power groups, vein shrinkage and energy per centimetre, are very similar.

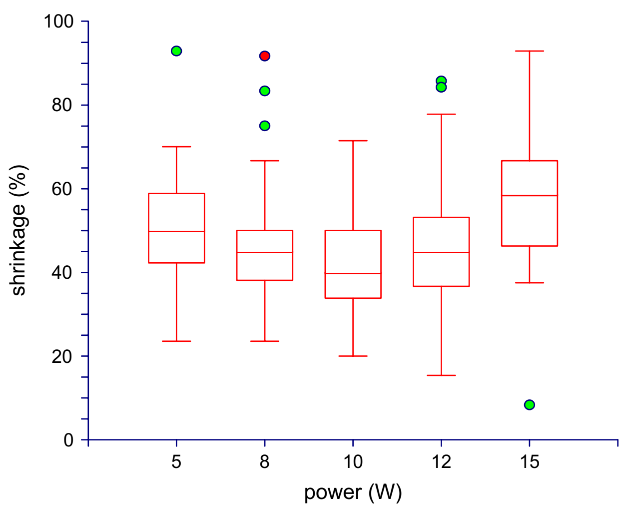

Fig. 3. Shrinkage obtained at different power values (horizontal box plot lines indicate medians and quartiles; extensions indicate 1.5 interquartile range, and circles indicate statistical outliers and extreme values.

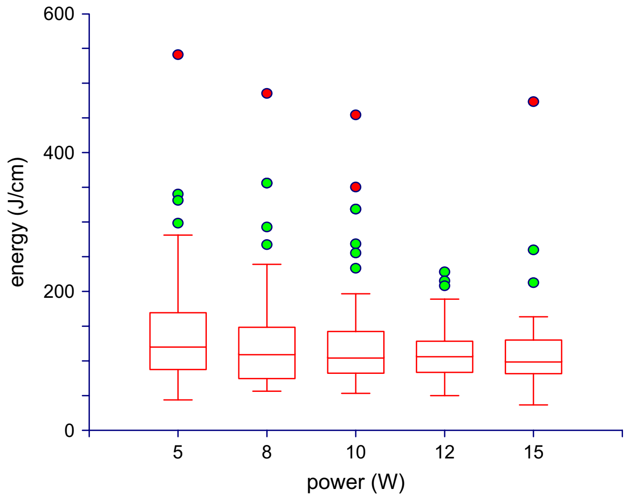

Fig. 4. Energy required to complete treatment compared at different power values (horizontal box plot lines indicate medians and quartiles; extensions indicate 1.5 interquartile range, and circles indicate statistical outliers and extreme values.

Fig. 6 shows the number of perforations observed in each power group. These data suggest that perforations are more frequent at higher power settings.

Discussion

The mechanism of laser-induced thermal damage consists of indirect heating of the vein wall by endovenous steam bubble formation, resulting in thrombotic

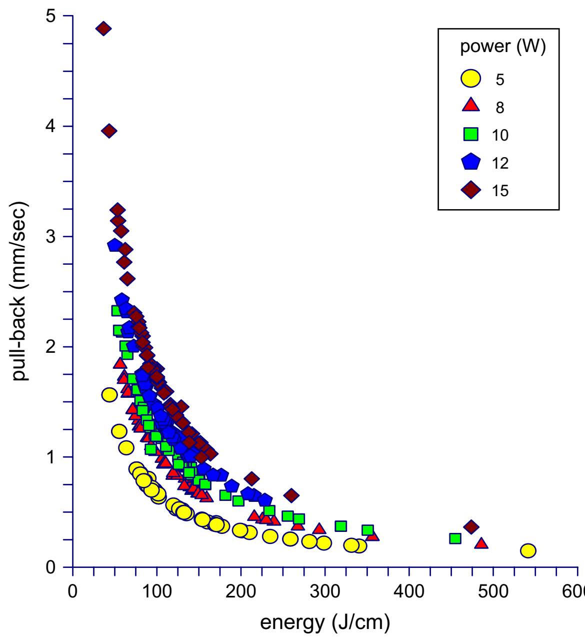

Fig. 5. Pull-back speed plotted against energy per centimetre.

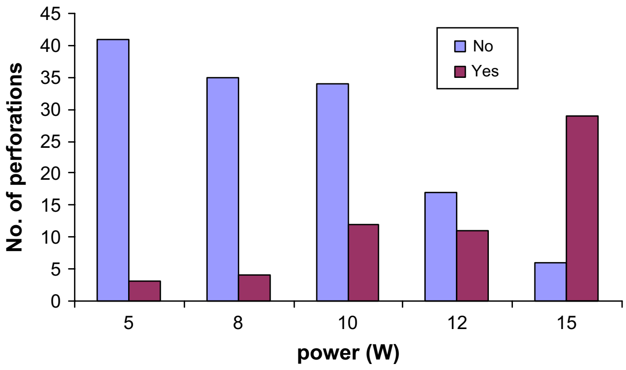

Fig. 6. Number of perforations plotted against power.

occlusion of the vessel,[2] and of direct damage of the vein wall as a consequence of closer contact between the laser fibre tip and the wall itself.[10] Shrinkage of the vein during thermal ablation plays a significant role in the immediate and late results of treatment.[11−13] Substantial shrinkage minimises the diameter of the remaining vein with little blood clot reducing the likelihood of recanalisation.

The middle layer of the venous wall (media) consists of smooth muscle fibres as well as an elastic connective tissue mesh. The venous wall is thinner, richer in collagen and poorer in myocytes and elastin than the arterial wall. Thermal shrinkage of collagenous tissue is a well known phenomenon. When collagen is heated to about 60 °C, it loses its highly organized structure and shrinks.[14,15] This process is described as degradation to gelatin or as denaturation. The thermal properties of collagen vary with the species of the animal and its age and the environmental conditions in which the animal lives.[16] The advantage of the current study compared to other animal studies which used goats, rabbits, pigs, sheeps and cows for experiments[1,4,6] is, that we used human varicose GSV for our research. We made many observations allowing reliable statistical analysis of our results.

Several studies have investigated the relationship between tissue behaviour, temperature, and duration of treatment, showing that shrinkage of collagen is temperature and time dependent.[17,18] A longer heating time optimises collagen shrinkage and subsequent vessel closure. There are also other factors that influence the magnitude of shrinkage, including treatment area, quality of tissue, orientation of collagen fibres, and distance from the laser fibre tip.[19] In this context, direct contact between the fibre tip and venous wall plays the most important role in venous shrinkage and damage with consequent lumen reduction and occlusion. Transfer of laser energy to the vein wall via direct circumferential contact is the predominant mechanism of action of endovenous laser. But excessive tissue damage with vein wall perforation may occur mainly at the point of direct contact between fibre tip and vessel wall.

Several studies have recommended application of higher power (even 30 W) in order to administer an effective amount (more than 90 J/cm) of laser energy to the venous wall.[7−10,20] The results of our study showed that the extent of thermal tissue effects measured by vein shrinkage does not increase when using higher laser power. Higher power settings may result in adverse factors including carbonisation of the fibre tip and possible wall perforation. The current study showed a significantly higher rate of perforations for the 15 W power group compared to lower power groups. We found that "slow" heating using a low or medium power (8 to 12 W) with slow pull-back speed of 0.2 to 2 mm/sec lead to the best shrinkage with fewest perforations. We found that after reaching the "threshold" energy of about 60 to 70 J/cm, shrinkage remains stable and further treatment is unnecessary. These findings are supported by the recent clinical study of Kim *et al*.[21] who obtained a satisfactory outcome with few complications and side effects by using an 11 W diode laser to deliver a total dose of 35 J/cm.

Conclusion

The present study supports the concept of "slow heating" during the endovenous laser treatment of varicose veins when assessing the outcome by vein shrinkage. We suggest that low or medium power settings (8 to 12 W) with slower pull-back speed of the laser fibre (0.2 to 2 mm/sec) will achieve vein shrinkage and adequate obliteration of veins. These are based on in vitro studies and would have to be confirmed in clinical practice.

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