TITLE **Total energy output from a diode endovenous laser ablation (EVLA) console does not vary depending on continuous or pulsed use – observed variations in power output may be due to sensor and power meter inertia.**

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ABSTRACT

Background: Endovenous laser ablation (EVLA) in truncal veins uses a constant power and smooth pull-back. In short veins (ie: incompetent perforator veins or neovascular tissue) power can be pulsed, allowing tissue cooling between pulses and reduction of thermal spread, protecting surrounding tissues. Power meter measurements suggest it takes over 2 seconds for a diode laser to reach 90% of maximum power output. Hence pulses shorter than 2 seconds might result in less energy being deposited into target tissues than indicated on the console. The aim of this study is to compare the power emitted from the tip of the laser device during continuous or pulsed use to that displayed on the console.

Methods: A 600 micron radial fibre connected to a 1470 nm EVLA diode console was fired at 10 W onto a sensor connected to a power meter, until 100 J had been emitted, for each of the following: continuous; pulsed 1 sec on, 1 sec off; pulsed 0.5 sec on, 1 sec off. Each was repeated 5 times, and the power recorded every 0.1 sec.

Results: The power meter recorded reduced peak powers in the pulsed experiments as expected, due to delay in reaching maximum output. However, all three protocols resulted in 94% of the total energy being emitted from the tip of the EVLA device. Analysis of the power data suggested that there was a delay in the power being recorded by the sensor and power meter both when activating and deactivating the laser.

Conclusion: Pulsing the laser power did not affect the total energy emitted from the tip of the EVLA device. The delay in reaching maximum power recorded by the power meter appears to be due to a sensor delay responding to incident laser energy, rather than the output from the laser diode and console.

INTRODUCTION

Endovenous laser ablation (EVLA) of incompetent truncal veins is one of the first line recommended treatments for symptomatic varicose veins.[1-3] This is usually performed by passing the laser device up the saphenous vein under ultrasound control to the point where the ablation is to start, and then withdrawing the device using a continuous pull-back.[4,5] It is usual to calculate the amount of energy deposited in each cm of vein, a value called the Linear Endovenous Energy Density (LEED).[6] The LEED is derived from the power used in Watts (J/sec) multiplied by the pull-back rate measured as number of seconds per cm (sec/cm). Hence the LEED is quoted in J/cm.

However, there are some instances where it is not wise to use a continuous pull-back, but it is more advisable to use a pulsed deposition of energy, such as in the TRLOP[7] or Hedgehog[8] techniques. The rationale of this is that the target vein still has the same energy deposited into it to cause transmural death and hence permanent ablation,[9] but the pauses between the pulses allows some cooling of the surrounding tissues, limiting the thermal spread and hence potential damage to surrounding tissues.

When laser output is measured by a power meter, the profile of how the power is delivered shows a ramping up of power from 0W to the target power, taking over 2 seconds in to reach the target power as displayed on the laser console (Figure 1). Hence, if the laser is pulsed in pulses less than 2 seconds, it is feasible to suggest that the target power is never achieved, and the maximum power of each pulse will be below the treatment power set on the console. Moreover, due to the time taken to ramp up the power for each pulse, it is possible that by pulsing the energy in this way, the total energy emitted from the device will end up being less than that displayed on the console.

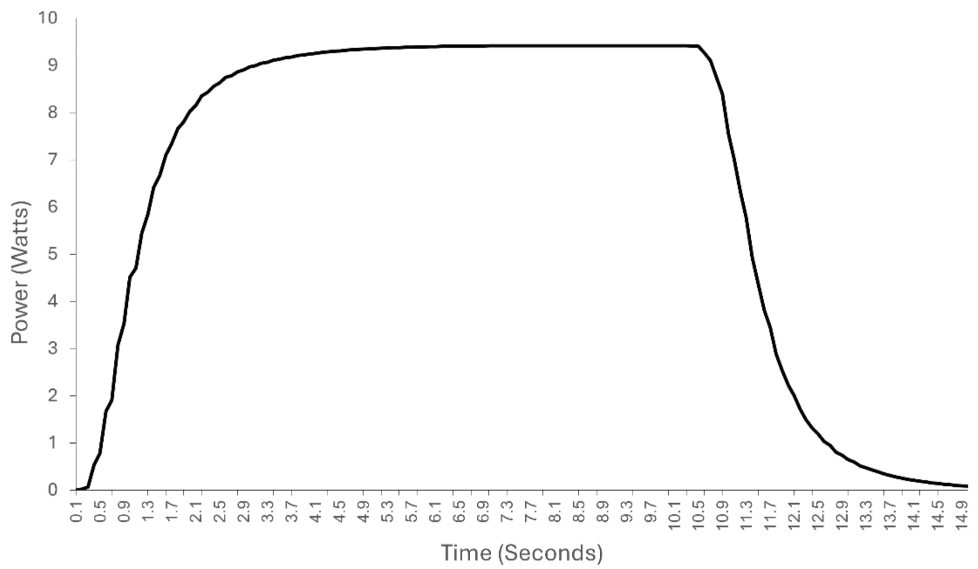

Figure 1: Energy output measured on the power meter from the tip of the laser device with the console set to 10W (see text for details of power meter and laser). The power takes several seconds to reach maximum output.

The aim of this study was to investigate the total energy emitted from the tip of the endovenous laser device during continuous and pulsed use, and to compare these results with the energy that the console reported had been emitted during the treatment.

METHODS

We chose to use a 1470nm diode laser (Vari-lase®, Vascular Solutions Inc., Minneapolis, Minnesota, USA) for this study, set to 10W continuous mode, with a 600μm single ring radial fibre (OBERON GmbH Fiber Technologies, Wildau, Germany) as the device (catheter) to be studied. The power meter that we used was the EO Premier Power/Energy Meter (Edmund Optics® Europe, York, UK) with a 0.19 - 20μm, 15W, Thermopile Power & Energy Detector (Edmund Optics® Europe, York, UK).

The laser device tip was positioned perpendicular to the detector, centred on the sensor and clamped in place so that the tip was almost touching the surface of the sensor. In this way, the radial beam was incident on the sensor, as such single ring radial beams have been shown to direct 80% of their energy at an angle of 70^0 to the fibre[10] ie: firing forwards and not perpendicular to the device axis.

Once set up as above, the laser was fired by depressing the footswitch, just as when used in the operating room. Full laser safety protocols were followed, with the study being performed in a locked room approved for laser use, the laser device tip and sensor placed behind a protective shield and all operators using appropriate eyewear in case of reflected beams.

Five repetitions of each of the following protocols were then performed and stored in the power meter for subsequent analysis:

1. Continuous – the laser was fired continuously at 10 W until the console showed that 100J had been delivered.
2. Pulsed 1 sec on and 1 sec off at 10 W until the console showed that 100 J had been delivered.
3. Pulsed 0.5 sec on and 1 sec off at 10 W until the console showed that 100 J had been delivered.

Although the operator attempted to make sure that exactly 100 J was the total in each case, as the laser was being controlled by a footswitch, there was naturally a small variance around this total energy, as noted in the results. Similarly, because the pulses were controlled by a footswitch, the timing was not exactly 1 sec or 0.5 sec respectively, but as near as could be obtained.

The power meter recorded the power incident on the sensor every 0.1 seconds and stored the data digitally. At the end of all the experiments, the data was downloaded onto a USB stick and then loaded into Excel (Version 2407 – Build 17830.20210 - Microsoft, USA) for analysis.

RESULTS

1 - Continuous

Each of the 5 experiments produced data that when plotted graphically, conformed to that shown in Figure 1. The actual values for each are shown in Table 1.

Test	Laser console total energy (J)	Power meter measured total energy (J)	Percentage of measured energy to console energy reading (%)	Time to reach total measured energy on power meter (secs)
A	105	98.9	94.2%	16.9
B	103	97.4	94.5%	16.8
C	103	96.7	93.9%	16.8
D	105	98.9	94.2%	16.8
E	102	95.9	94.0%	16.6
Mean	103.6	97.6	94.2%	16.8

Table 1: Each of the 5 experiments showed very similar results. Of note, the power meter measured only 94.2% of the total energy that was recorded as having been used on the laser console. Furthermore, the time to emit the total energy was a mean of 16.8 seconds – whereas at 10 W, it should only take 10 seconds to emit 100 J.

There was very little variation between the 5 continuous experiments. The mean power measured by the power meter was 97.6 J, compared to the total energy that was measured as having been emitted by the console of 103.6 J. This represents an actual energy emission of 94.2% of the power recorded as having been emitted on the console. Further, as the laser power was set to 10 W, this means that 10 J were being emitted from the diode in the console every second. Hence the total 100 J should have been emitted in 10 seconds. However, according to the energy being recorded by the sensor over time, it took a mean of 16.2 seconds emit the total energy. This seems to support the point made in the introduction and shown in Figure 1, that there is a delay in the power building up to the maximum power output, of well over 2 seconds.

2 - Pulsed 1 sec on and 1 sec off

The data from each of the 5 experiments is typified by that shown in Figure 2. As the pulses are only 1 second long, they do not reach the power indicated on the console, as predicted above. The peak power achieved is in the region of 7 W. As can be seen on the Y-axis, the time taken to achieve the 100 J of energy deposition is much longer than when a continuous power is applied. This is tabulated in Table 2.

However, the mean laser energy emitted as recorded by the console was 101.4 J, and that measured by the power meter was 96.6 J – 94.3% of that recorded on the console. This is the same power loss in the system as found in the continuous firing of the laser, showing no reduction in the total power emitted from the device tip as measured by the power meter, due to the pulsing of the energy.

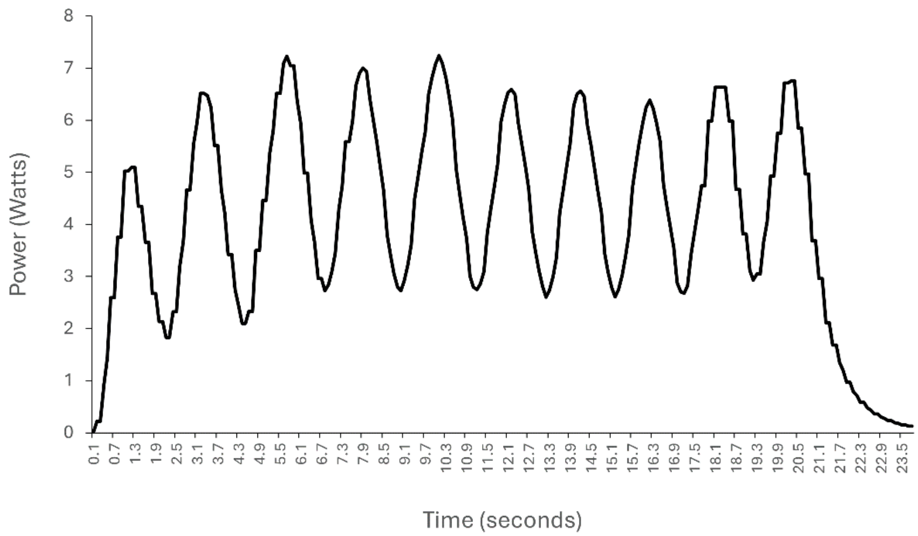

Figure 2: A graph of power emitted from the laser device tip, measured by the power meter, over time, when the laser is pulsed using the footswitch at a setting of 10 W with 1 second on and 1 second off. Due to the time taken to build up to full power (as in Figure 1), the maximum power achieved is only 7 W.

Furthermore, the expected time for 100 J to be emitted at 10 W and pulsed one second on and one second off would be 20 seconds – and the actual measured time was 24.0 seconds (Table 2). This is closer to the expected time as compared to the continuous firing of the laser, and this will be discussed later.

Test	Laser console total energy (J)	Power meter measured total energy (J)	Percentage of measured energy to console energy reading (%)	Time to reach total measured energy on power meter (secs)
A	104	97.9	94.1%	22.8
B	100	94.7	94.7%	26.0
C	97	91.4	94.3%	23.8
D	103	97.5	94.7%	23.8
E	103	96.6	93.8%	23.8
Mean	101.4	95.6	94.3%	24.0

Table 2: Each of the 5 experiments again showed very similar results. The power meter measured 94.3% of the total energy that was recorded on the laser console. The time to emit the total energy was a mean of 24.0 seconds – whereas at 10 W and pulsed 1 second on and 1 second off, it should have taken 20 seconds to emit 100 J.

3 - Pulsed 0.5 sec on and 1 sec off

One of the experiments had corrupted date and so there were only 4 records to analyse. However, as there was so little difference between the results of the 4 experiments, we decided to accept these rather than repeat the experiment just to obtain the 5th data set.

As with the 1 second pulsing, the 0.5 second pulses resulted in a lower maximum power output due to the lag in getting to full power. In this case, the maximum power output was approximately 5 W (Figure 3).

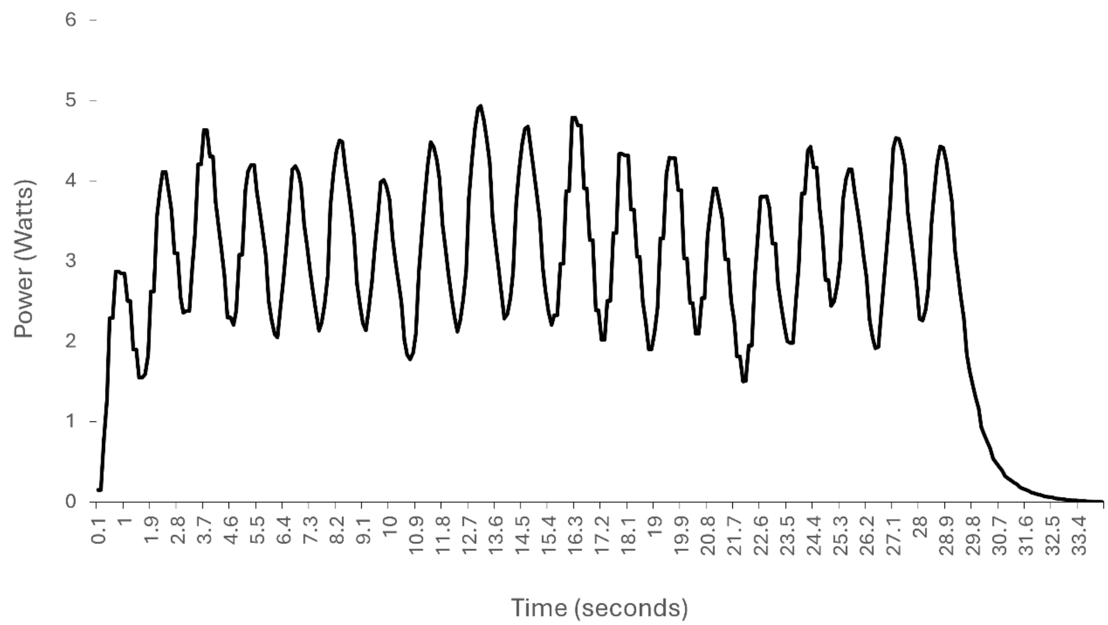

Figure 3: A graph of power emitted from the laser device tip, measured by the power meter, over time, when the laser is pulsed using the footswitch at a setting of 10 W with 0.5 seconds on and 1 second off. Due to the time taken to build up to full power (as in Figure 1), the maximum power achieved is only 5 W.

Once again, the percentage of total energy emitted as measured by the power meter was 93.7% of the total energy registered as being emitted by the console (Table 3). This is statistically the same as both other experiments. The expected time taken to emit the 100 J (as per the console) at 10 W for 0.5 seconds and then 1 second pause would be 30 seconds (as 5 W would be emitted every 1.5 seconds). The mean measured was 34.9 seconds.

Test	Laser console total energy (J)	Power meter measured total energy (J)	Percentage of measured energy to console energy reading (%)	Time to reach total measured energy on power meter (secs)
A	99	94.1	95.0%	35.8
B	99	93.0	94.0%	34.6
C	100	93.9	93.9%	34.8
D	103	94.8	92.0%	34.2
Mean	100.3	93.9	93.7%	34.9

Table 3: Data from one of the 5 experiments was corrupted on transfer from the power meter to a computer to analyse. However, as the other data showed very similar values, it was decided that a repeat of just one experiment at one setting would not make any material difference to the conclusions of the study. Again, the power meter measured 93.73% of the total energy that was recorded on the laser console. In this case, the time to emit the total energy was a mean of 34.9 seconds – whereas at 10 W and pulsed 0.5 seconds on and 1 second off, it should have taken 30 seconds to emit 100 J.

DISCUSSION

In EVLA, tissue damage (or “ablation”) is dependent on the amount of energy transmitted from the device and into the vein wall, independent of time, as evidenced by LEED being measured in J/cm.[6] Of course this is only true within certain limits of the power used, as previously documented.[11,12] Within these therapeutic powers, the role of introducing pauses in the laser treatment is merely to reduce thermal spread to surrounding tissue by allowing time for heat dissipation and cooling. This is important when treating small veins that are near nerves or the skin, such as a below knee incompetent perforating veins (IPV) in the TRLOP technique,[7] or neovascular tissue in the hedgehog technique.[8]

Although we did find the delay in getting to the full power, as shown in Figure 1 and noted in the introduction, we were surprised that this didn’t translate into a reduction in the total energy being emitted compared to the console readout of energy emitted, when the pulsed protocols were followed. Therefore, we decided to look into this delay in more detail.

As the increase in power is curved in an exponential type pattern, it was appropriate to measure when 90% of the maximum power had been reached (Figure 4). This turned out to occur at 2.3 seconds from the onset of firing the laser.

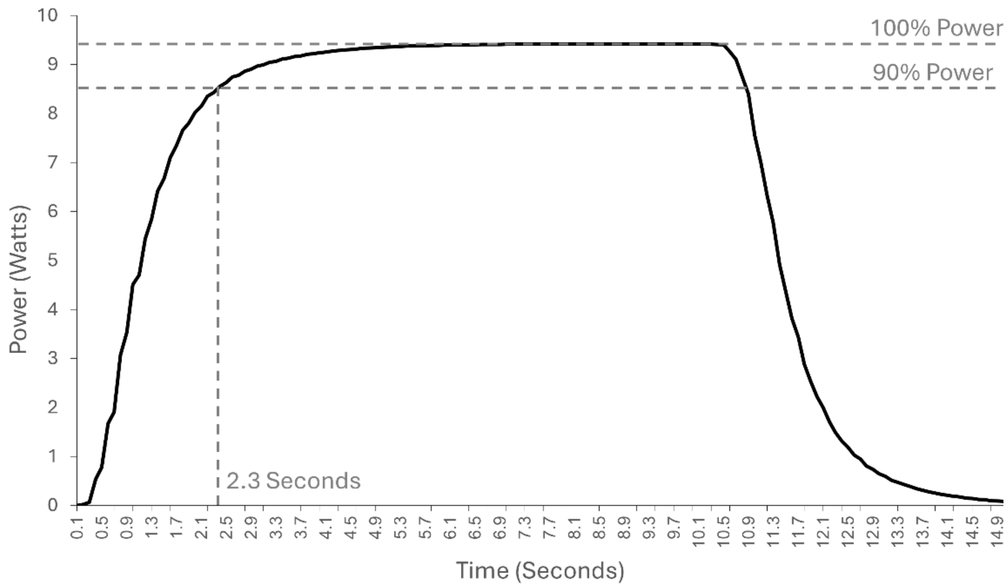

Figure 4: This graph shows that it takes 2.3 seconds for the power being emitted from the tip of the laser device to reach 90% of the maximum power.

However, when the laser is stopped at the end of the treatment (when 100 J of energy had been emitted) the foot switch is deactivated, and the laser stops immediately. Despite this, the readings from the power meter do not show a sudden stopping of power being emitted, but show another exponential type curve, the inverse of the onset of power (Figure 5).

The most likely explanation for the power meter to be registering power still being emitted from the tip of the laser device, even after the laser had been deactivated, is that the sensor and power meter used for this study do not react immediately to the power incident on the sensor.

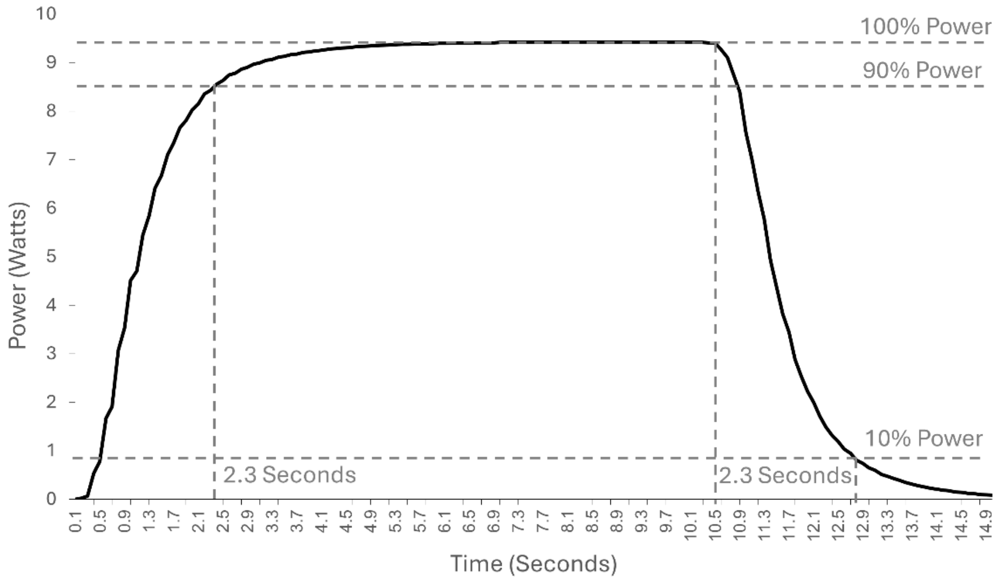

Figure 5: Further analysis of the same graph as in Figure 4, showing the power emitted from the tip of the laser device as measured by the power meter, but now showing the lag of residual power "dying away" once the laser was deactivated. It took 2.3 seconds for a reduction of 90% of the power according to the power meter – the inverse of the power build up when the laser was activated.

When the laser energy first hits the sensor, the reported rise in power is identical, but inverse, to the fall in power when the laser is deactivated. When this is added to the fact that the total energy emitted is as expected, without any energy loss from the pulsing of the laser, then it is clear that there is a delay from when laser energy hits the sensor, and when it is recorded by the power meter.

This would also explain why the peak powers in Figures 2 and 3 are reduced from the 10 W displayed on the console and the 9.4 W measured by the power meter for continuous firing of the laser, but the total energy emitted from the tip of the laser device is still the same as that for the continuous firing of the laser, and the total time to achieve this is the same as what we calculated as being expected, but with a few extra seconds which corresponds to the delay in the reaction of the sensor and power meter to record the energy.

One obvious limitation of this study is that we only measured one wavelength, one laser console and device, and used one sensor and power meter, so different equipment might give different responses to the incident laser energy. However, despite the fact that we could not trust the data on the exact energy being emitted from the tip of the laser device during the initial few seconds of activating or deactivating the laser due to the inertia of the sensor and power meter to responding, we were able to confirm that there was no loss in actual laser power being emitted when the energy is pulsed.

In conclusion, pulsing the laser power with gaps in between pulses to allow tissue cooling and to reduce thermal spread does not affect the total energy being emitted from the tip of the laser device. The delay in reaching maximum power as recorded by the power meter, appears to be due to an inertial delay of the sensor responding to incident laser energy, rather than any property of the output from the laser diode and console.

CONTRIBUTIONS

Conception or design of the work	MSW
Data collection	OFB, MSW
Data analysis and interpretation	OFB, MSW
Drafting the article	MSW
Critical revision of the article	OFB
Final approval of the version to be published	OFB, MSW

DECLARATIONS

No declarations relevant

CONFLICTING INTERESTS

None

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ETHICAL APPROVAL

Not relevant

GUARANTOR

Prof Mark S Whiteley

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