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Evaluation of Pulse-Duration on Purpuric Threshold Using Extended Pulse Pulsed Dye Laser (Cynosure V-Star)

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Background and Objectives: Pulsed dye lasers (PDL) with extended pulse-durations create new opportunities in the treatment of vascular lesions. Development of extended pulse methods requires understanding of tissue effects of extended pulse-durations. We evaluated tissue effects of extended pulse-duration PDL (EPDL) with cooling. Effects of increasing pulse-duration, fluence, and multiple passes were evaluated to determine purpuric threshold and delayed purpuric response.

Study Design/Patients and Methods: Ten patients were treated with EPDL and air-cooling on normal buttocks skin. Exposure pulse-durations of 0.5, 2, 20, and 40 milliseconds and increasing fluences 3–20 J/cm^2, pulse-duration dependent. Exposures were evaluated 0.5, 1, and 24 or 48 hours determining purpuric threshold and side effects.

Results: Immediate purpuric threshold increased from 6.2 to 8, 10.4, and 13.8 J/cm^2 at pulse-durations of 0.5, 2, 20, and 40 milliseconds, respectively. Purpuric threshold dropped after 24 hours to 5.2, 7.1, 9.3, and 11.9 J/cm^2, respectively. Multi-pass treatment lowered purpuric threshold by 1 J/cm^2. EPDL purpura resolved in less time than traditional PDL. No side effects were noted.

Conclusions: EPDL exhibits increasing purpuric threshold with increasing pulse-durations, and risk of delayed onset of purpura. Lasers Surg. Med. 31:363–366, 2002.

Key words: vascular lesion; selective photothermolysis; purpura

INTRODUCTION

The pulse dye laser (PDL) was the first laser designed using the concept of selective photothermolysis for the treatment of vascular lesions [1,2]. Since its inception, the PDL has become the standard by which all vascular lasers are evaluated. The indications treated with the PDL are numerous and still expanding, One drawback of the PDL has been the presence of purpura after typical treatments. Although the purpura is a transient side effect, it is often disturbing to the patient. The early PDL provided a laser pulse of 0.5 milliseconds duration. It was generally believed that longer pulse-duration would reduce the purpuric response. Commercial dye lasers with output pulse-duration of 1.5 milliseconds have been available for some time. These have not demonstrated sufficient reduction in purpuric response at typical therapeutic fluence settings to make them appealing for cosmetic applications. Dierickx et al. investigated the role of pulse-duration on the onset of purpura. In their work, they used two laser pulses separated by an adjustable time interval [3]. The fluence that resulted in the onset of purpura was recorded as a function of temporal pulse separation. They concluded that laser pulses in the 1–10 milliseconds pulse-duration range would greatly reduce the purpuric response. Recently, a new family of higher energy PDL have become available that can provide laser pulses of duration up to 40 milliseconds.

The new lasers differ from previous dye lasers in their pulse format. Earlier dye lasers provided a single pulse of a specified duration. The new lasers provide several shorter sub-pulses that extend over a time interval of up to 40 milliseconds (Fig. 1). This difference and the extended time interval operation suggested that purpuric response with these lasers be investigated.

PATIENTS AND METHODS

A long PDL (V-Star, Cynosure, Inc., Chelmsford, MA) was used to investigate the onset of purpura. The laser is a long PDL whose output wavelength is 595 nm. Multiple spot sizes were investigated, as purpuric fluences could not be attained with the 10-mm handpiece in all cases, as the V-Star laser maximum fluence available with a 10 mm handpiece is 10 J/cm^2. Cooling was provided by means of chilled air (SmartCool, Cynosure, Inc.) flowing over the exposure region before, during, and after laser irradiation.

Ten patients were involved in this study. Each patient was exposed to a series of laser pulses. All four laser pulse-durations (0.5, 2, 20, 40 milliseconds) were investigated using two spot sizes, 7 and 10 mm. All treatments were done in the buttocks region. Each treatment consisted of a series of single laser pulses whose fluence was varied in steps of ~1 J/cm^2 up to the maximum fluence available. One such series was carried out for each of the four available pulse-durations. These were then repeated using the

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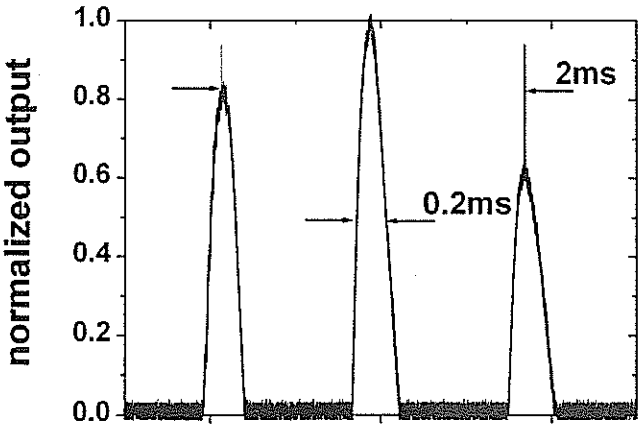


Fig. 1. Compound laser pulse format: 2 milliseconds pulse measured from PhotoGenica V-Star.

second handpiece size. Digital photographs were taken at 0.5, 1, 24, and/or 48 hours post treatment. In most cases, photographs were taken at either 0.5 or 1 hour and at either 24 or 48 hours. Purpuric threshold was determined by evaluating the pictures and was defined as the fluence at which any non-transient redness or bruising was evident.

RESULTS

The fluence ranges covered in this study include exposure well below onset and in most cases up to well above the onset of purpura. Figure 2a–c show a typical set of photos taken at the time intervals given above. From these, the fluence at the onset of purpura can be estimated. Typically, the fluence at the onset of purpura decreases over the first 24 hours then remains essentially constant over the next 24 hours. We noticed that the character of the purpura is somewhat different, more red and less purple or maroon than our previous experience with dye lasers. Figure 3a shows a summary of the data for all ten patients using a 7 mm exposure spot size. The error bars are ± 1 standard deviation of the data where enough data points were available. The laser fluence at the onset of purpura clearly increases with increasing pulse-duration. Using the laser at 40 milliseconds pulse-duration, the fluence at the onset of purpura is about twice that observed at 0.5 milliseconds pulse-duration.

A similar result is observed using a 10 mm exposure spot size. Figure 3b shows a summary of the data for all ten patients. Again, error bars are ± 1 standard deviation of the data where enough data points were available. The maximum fluence available using this handpiece is 10 J/cm^2. When the 40 milliseconds pulse was used, some of the patients did not exhibit purpura at any fluence up to this limit and were excluded from the data set.

THEORY OF OPERATION

The new long PDLs use a compound pulse format. The long pulse consists of several sub-pulses delivered over a long time interval. It is generally accepted that purpura is

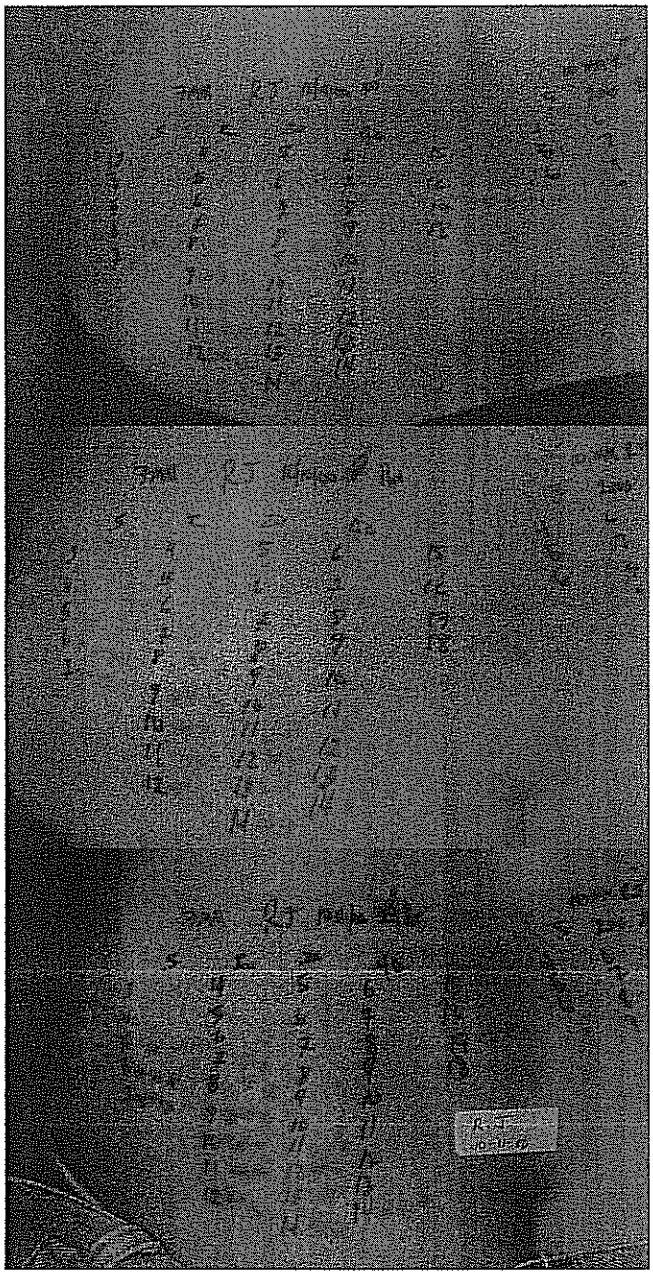
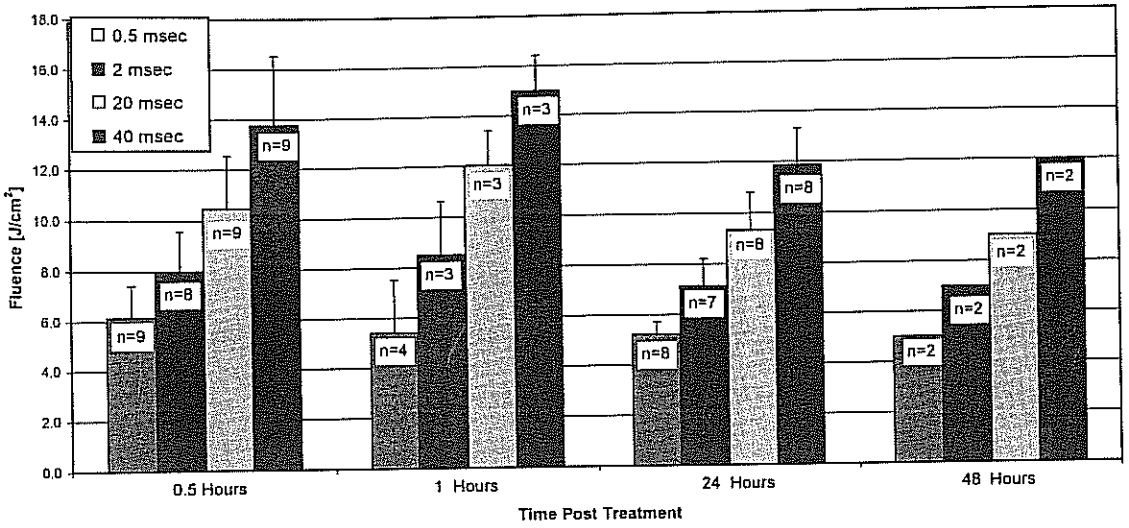
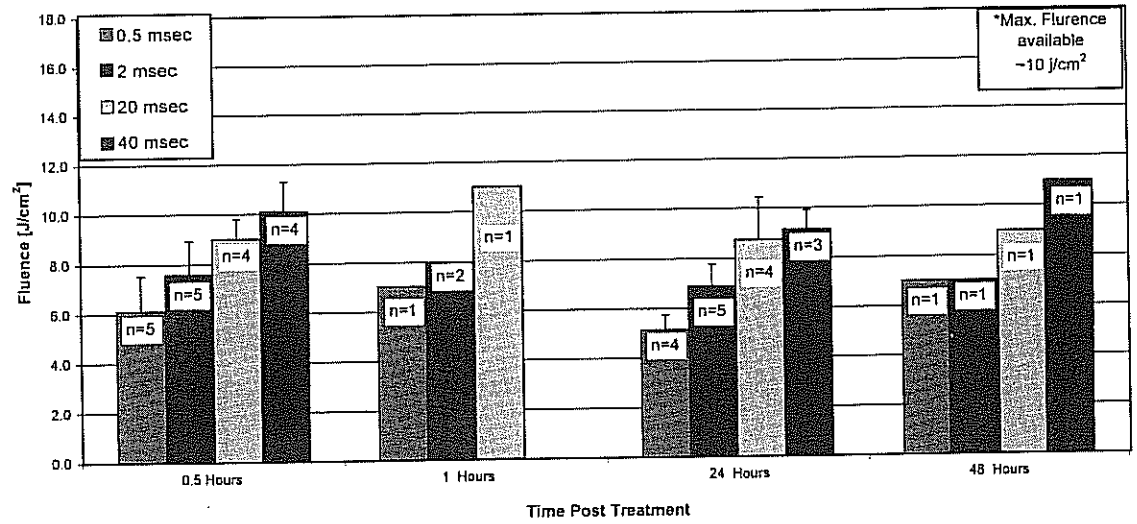


Fig. 2. Five hundred and ninety five nanometers, 7 mm test spots, (**a**) 0.5 hours, (**b**) 1 hour, (**c**) 24 hours after laser exposure.

caused by damage imparted to small capillaries throughout the normal dermis [4]. These vessels are of diameters in the range from 20 to 60 μm [4]. When widely spaced sub-pulses are used to make up a long pulse, these vessels can cool substantially during the time interval between sub-pulses. Larger vessels of diameters 300 μm or more as are common in telangiectasias on the other hand are more nearly heated cumulatively. We analyzed theoretically the effect of the compound pulse used in the V-Star laser on vessels responsible for purpura. In the analysis, we assume the laser tissue interaction is largely a heating process. In that case, the time evolution of the temperature in a



a



b

Fig. 3. Summary purpuric threshold observed for (**a**) 7 and (**b**) 10 mm spot size exposures to 595 nm dye laser.

vessel can be determined by solving the heat transport equation [5].

$$\kappa\nabla^2 T(r,t) - \partial T(r,t)/\partial t = h(r,t) \qquad (1)$$

Here the vessels are approximated by simple cylinders and T(r,t) is the temperature at time t and radial coordinate r. h(r,t) is the heat source, that is to say, the effect of laser pulse. In the case of the V-Star laser, the compound pulse (2, 20, 40 milliseconds pulses only) consists of three subpulses each 0.2 milliseconds full width half max. Equation 1 is a partial differential equation that can be solved analytically only for a few particular forms [5] of the heating function h(r,t). Fortunately, some of the cases that can be solved resemble, exactly, the heating profile of the V-Star laser compound pulse. Here we used an approximate solution based on the assumptions that the heat source function can be approximated as a product of a cylindrical Gaussian spatial distribution centered in the blood vessel and a temporal function consisting of three rectangular pulses with 0.2 milliseconds pulse duration. This approximation allows the solution to Equation 1 to be reduced to a simple spread sheet and many different fluence levels and pulse formats to be analyzed quickly. (The details of the mathematical analysis will be published in a separate paper.)

The approximate analytical solution of Equation 1, as discussed above, allows for the calculation of the blood

vessel temperature rise for various laser pulse formats. However, direct comparison with experimental data would be very difficult because it would require measurements of the temperature of small blood vessels and comparison to the various pulse formats. Usually, the experimentally measured clinical data is the purpura threshold fluence. Under the assumption that the peak target temperature determines the extent of target damage, the clinical observation of threshold purpura would mean that the peak target temperature reached a threshold value that is the same for all pulse durations. Therefore, it is possible to normalize the purpuric fluence threshold for the extended pulse durations, and eliminate the threshold damage temperature, using a benchmark pulse with a known purpuric fluence threshold. The 0.5 milliseconds pulse duration was chosen as the benchmark for comparison due to its long clinical history [4].

The normalized damage threshold can be calculated for a given pulse format, and vessel size. This has been done for pulse durations between 0.5 and 42 milliseconds and for vessel diameters ranging from 20 to 60 μm. These are the vessels assumed to be responsible for purpura (Fig. 4). The gray shaded region on Figure 4 corresponds to the range of vessels between 20 and 60 μm. For pulse durations of 30 milliseconds and longer, the upper bound of the range is determined by the damage threshold in the 60 μm vessels. For pulse durations shorter than 30 milliseconds, the upper bound is determined by vessels smaller than 60 μm in diameter. Variations of the upper bound are due to the different rate of cooling of the various vessel sizes. For pulse durations longer than 30 milliseconds, all of the considered vessel diameters cool sufficiently in the time period between the individual sub-pulses. For the shorter pulse duration, the larger blood vessels retain more heat from the preceding sub-pulse and that lowers their damage threshold.

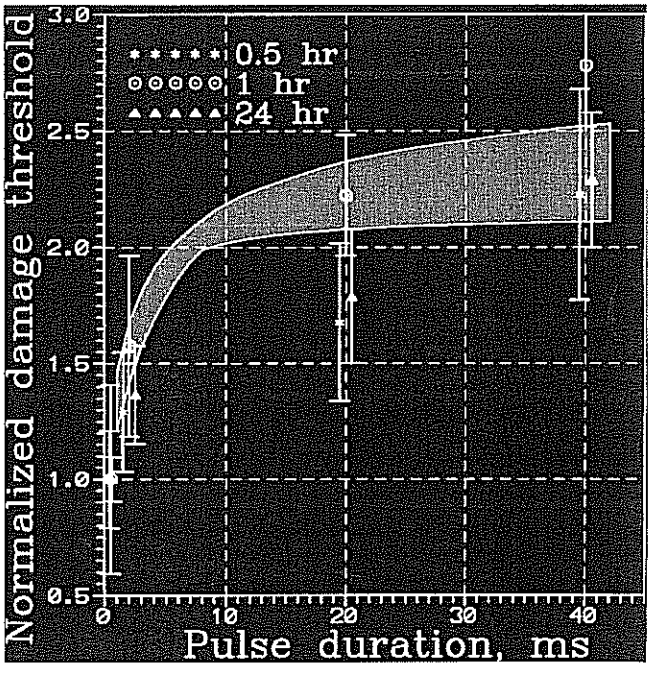


Fig. 4. Purpuric threshold model solved for the case of three sub-pulses each 0.2 milliseconds long, up to 40 milliseconds total pulse-duration (V-Star case). The gray region outlines the calculated normalized damage threshold energies for targets with diameters between 20 and 60 mm.

Also shown in Figure 4 are the results of the ten patient study. The patient data for the purpuric threshold was normalized by dividing by the purpuric threshold fluence for the 0.5 milliseconds pulse. It is evident from the figure that good agreement exists between the measured purpuric threshold and the estimated range of the threshold as calculated from the model.

DISCUSSION AND CONCLUSIONS

The threshold fluence for purpura using the new long compound PDLs greatly increases with increasing pulse-duration. At 40 milliseconds pulse-duration, the threshold fluence for purpura is about twice that observed with the 0.5 milliseconds pulse-duration. The increase in threshold is consistent with expected simple heating of vessels whose diameter are in the range 20–60 μm.

Theory predicts increasing purpuric threshold with increasing pulse-duration. In the case of a compound pulse format, the expected increase in threshold is not as great as with a true, long-pulse laser. Theoretical modeling provides predictions as to the degree of increase in threshold, which has been substantiated by clinical experience with the compound pulse format. Our model suggests that a true long-pulse laser with a 40 milliseconds pulse may offer an eightfold increase of the purpuric threshold. However, such laser for clinical use is not practical to build with current technology.

Our model suggests that the 40 milliseconds duration of the compound pulses are optimal for the treatment of larger vessels 0.3–1.2 mm. The damage to the surrounding smaller vessels by the sub pulses in these large pulses is an important issue that must be considered in any clinical situation. This change in the population in affected vessels may also explain the difference we noted in the character of purpura. Hopefully further clinical studies will demonstrate methods for selectively damaging only the larger targeted vessels.

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