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Technical note

Determination of pulse profile characteristics of multi spot retinal photocoagulation lasers

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ABSTRACT

A system is described for determination of discrete pulse train characteristics of multi spot laser delivery systems for retinal photocoagulation. While photodiodes provide an ideal detection mechanism, measurement artifacts can potentially be introduced by the spatial pattern of the delivered beam relative to a discrete photodiode element. This problem was overcome by use of an integrating sphere to produce a uniform light field at the site of the photodiode detector. A basic current driven photodiode detection circuit incorporating an operational amplifier was used to generate a signal captured by a commercially available USB interface device at a rate of 10 kHz. Studies were undertaken of a Topcon Pascal Streamline laser system with output at a wavelength of 577 nm (yellow). This laser features the proprietary feature of 'Endpoint Management' ™ where pulses can be delivered as 100% of set energy levels with visible reaction on the retina and also at a reduced energy level to create potentially non visible but clinically effective lesions. Using the pulse train measurement device it was identified that the 'Endpoint Management' ™ delivery mode of pulses of lower energy was achieved by reducing the pulse duration of pulses for non-visible effect pulses while maintaining consistent beam power levels within the delivered pulse profile. The effect of eye geometry in determining safety and effectiveness of multi spot laser delivery for retinal photocoagulation is discussed.

1. Introduction

The emergence of multi spot scanning lasers for retinal photocoagulation has introduced more complex modes of device delivery. Some advantages associated with this technique include more rapid patient treatment times, the potential of reduced patient discomfort and the reduction in subsequent 'creep' of lesion size following treatment [1–3]. The reduction in pain typically experienced by patients using the 577 nm wavelength has been attributed in part to the reduced absorption by the yellow xanthophyll retinal pigment [4]. Specific studies have also been reported indicating the general safety and efficacy of multi spot scanning lasers [5,6] though there as yet have been no large multi-centred trials comparing conventional single spot with multi-spot retinal photocoagulation technologies. A useful review of modern retinal laser techniques, including image guided systems with eye tracking, is described by Kozak and Luttrull [7].

As yet no device standards have been developed to characterise the performance limits of multi spot scanning ophthalmic lasers with respect, for example, to the accuracy of pulse timing and the level of delivered power within individual pulses as part of a pulse sequence. Appropriate measurement technologies, however, are required to allow verification of such complex pulse profiles. Basic devices designed for measurement of, for example, single laser pulses [8] are not appropriate.

Measurements of delivered pulse profiles were initially made using a Pascal Steamline laser (Topcon, Santa Clara, USA) with output at 577 nm (yellow) and where available spot diameters were 100, 200 and 400 μm. Access was available to two such laser systems in routine clinical use. A selection of the pattern modes available with this laser is indicated in Fig. 1. It is noted that the minimum delivery times for various indicated pattern modalities in Fig. 1 extend up to 0.8 s – which will make such delivery modes involving large numbers of discrete pulses more susceptible to patient movement. This characteristic mode of delivery with multi spot lasers is for pulse durations of around 10 ms or 20 ms which tend to preferentially develop lesions in the upper layer of the retina and reduce involvement of deeper photoreceptor cells. It is the relatively short value of

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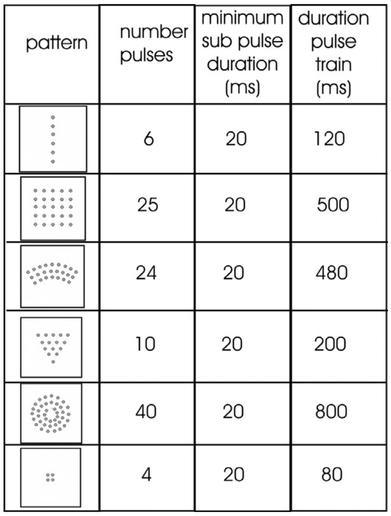

pattern	number pulses	minimum sub pulse duration (ms)	duration pulse train (ms)
	6	20	120
	25	20	500
	24	20	480
	10	20	200
	40	20	800
	4	20	80

Fig. 1. Typical pattern set at default 20 ms pulse duration.

individual pulse durations within the pulse train of multi spot lasers which make them practical clinical tools.

2. Method

2.1. Detection system

A series of measurements was initially undertaken using a device previously developed for spectral characterisation of intense pulsed light sources [9] and where a specific single channel of this device with a selected filter sensitivity at around 577 nm was utilised. It was identified, however, that device sensitivity was significantly influenced by the position of the scanning beam relative to the sensitive photodiode element. Subsequently an IS3-ODM integrating sphere (Bentham Instruments, Reading, UK) was used to create a uniform light intensity profile over the photodiode detection element (OSD5-5T Centronic Ltd., Croydon, UK). The photodiode was selected with a relatively large detection area since it could be readily positioned over the exit port of the integrating sphere.

Signal generation was undertaken by means of a basic photodiode detection circuit using an operational amplifier which converted the photodiode current to an output voltage through a gain resistor. Data capture was undertaken using a USB interface device 1208-FS (Measurement Computing, Norton, USA). Software available with the USB device allowed capture of data and automatic export to Excel ® for subsequent analysis. The detection system is indicated schematically in Fig. 2.

2.2. Detection system sensitivity

Eq. (1) summarises the signal sensitivity characteristics of the detection system.

$$V_{out}(t) = (R_{load}\,Reflef_{eff}\,Pdiode_{area}\,Pdiode_{sensit}\,Power_{laser}(t))/(4\pi\,Radius^2) \quad (1)$$

where $V_{out}(t)$ is the output voltage of photodiode detection circuit at time t, R_{load} is the gain resistor value in the photodiode circuit, $Power_{laser}(t)$ is the output power of a specific laser pulse element at time t, $Pdiode_{area}$ is the area of the photodiode element, $Pdiode_{sensit}$ is the sensitivity of the photodiode, $Reflef_{eff}$ is the effective fractional reflectance of the integrating sphere and Radius is the internal radius of the integrating sphere. Values of these parameters with relevant units are summarised in Table 1. It is important in the range of operation of the photodiode circuit that it does not saturate the operational amplifier. The laser is typically operated at the lowest available output power setting of 30 mW. There are also considerations of the angular sensitivity of the photodiode element which have not been included. The predicted sensitivity of the system was essentially confirmed by subsequent observations.

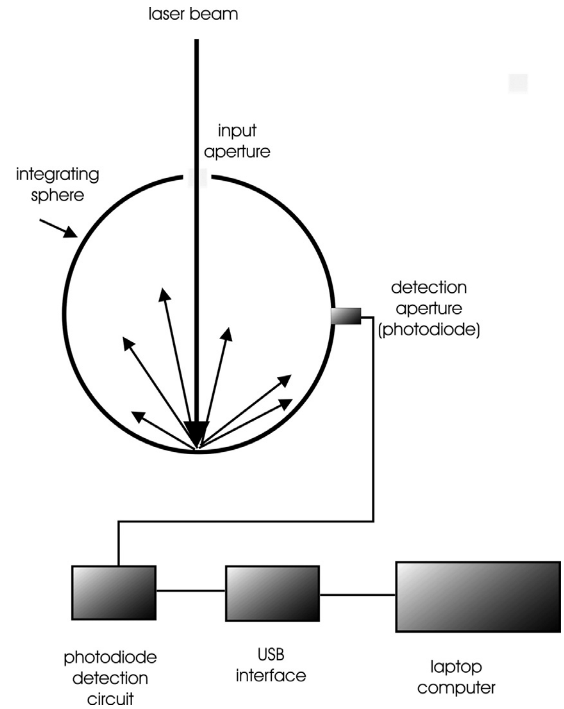

Fig. 2. Schematic of photodiode detection system.

Table 1
Parameters of the photodiode detection system.

Parameter	Value	Units
R_{load}	600k	Ohms
$Reflef_{eff}$	0.98	–
$Pdiode_{area}$	5.0	mm^2
Radius	3.8	Cm
$Pdiode_{sensit}$ @ 577 nm	0.38	A/W
$Power_{laser}$ (typical)	0.03	W
Device sensitivity	0.08	V/mW

3. Results

3.1. Verification of Endpoint Management^{TM} mode: Pascal Streamline laser

In the Pascal Streamline laser system, so called Endpoint Management ^{TM} within a pulse train can be implemented where typically a subset of landmark or marker pulses are delivered at 100% of indicated pulse energy and a subset of pulses are delivered at a specific percentage of nominal set pulse energy. The mode of pulse modulation is achieved by reducing the pulse width of pulses so that for example, a pulse train could contain 'landmark' pulses of width 20 ms (at nominal 100% power) and separate treatment pulses with Endpoint Management^{TM} value of 80% which would create pulses of pulse width 16 ms at a level of beam power which is constant during delivery of the pulse train. Fig. 3a indicates a pulse profile for five of 80% and four of 95% pulses derived from a 3 × 3 array and where it is evident that the reduced pulse energy is derived from a reduced pulse width. Fig. 3b indicates the pulse profile for a 50% Endpoint Management ^{TM} profile for the 3 × 3 array profile.