Measurement of the main and critical parameters for optimal laser treatment of heart disease

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Abstract. Laser light is frequently used in the diagnosis and treatment of patients. As in traditional treatments such as medication, bypass surgery, and minimally invasive ways, laser treatment can also fail and present serious side effects. The true reason for laser treatment failure or the side effects thereof, remains unknown. From the literature review conducted, and experimental results generated we conclude that an optimal laser treatment for coronary artery disease (named heart disease) can be obtained if certain critical parameters are correctly measured and understood. These parameters include the laser power, the laser beam profile, the fluence rate, the treatment time, as well as the absorption and scattering coefficients of the target treatment tissue. Therefore, this paper proposes different, accurate methods for the measurement of these critical parameters to determine the optimal laser treatment of heart disease with a minimal risk of side effects. The results from the measurement of absorption and scattering properties can be used in a computer simulation package to predict the fluence rate. The computing technique is a program based on the random number (Monte Carlo) process and probability statistics to track the propagation of photons through a biological tissue.

1. Introduction

Laser light treatment modalities in the health and beauty fields are increasing rapidly worldwide. Some of these modalities need to penetrate through some layers of the target treatment organ [1]. A large number of them fail to achieve the goal and sometimes bring serious side effects such as burning the no-atherosclerotic cells, scarring and permanent depigmentation [2]. Some succeed after a very long time of treatment [3]. Until now, the reasons for laser light treatment failure are not well understood.

The aim of this paper is to address these challenges, and to provide a method to address the optimal laser treatment of heart disease or any disease with reduced risk of side effects. For this, the authors estimate that the better measurement of the six key parameters (the initial laser power, the laser beam profile, the fluence rate, treatment time, and the absorption and scattering coefficients of the tissue) and better application of the results (from the measurements) to patients will bring the expected results. The main challenge in the measurement of these critical parameters remains on the methods used for achieving the correct results. Another challenge in the application can be attributed to the quality of the clinicians in charge of the patients' treatment.

2. The parameters involved in laser treatment of heart disease

A good understanding of the parameters involved in the process remains critical for the optimal use of laser as a treatment modality [4]. The optical properties of the coronary artery tissue (CAT) and the laser light propagation within the three layers of the arteries have been investigated by a number of researchers, [5]; [6]; [7]; [8]; [9]; [10]; [11]; [12; [13]; [14]; [15]; [16]; [17]. These properties are important as they determine the reduction in the laser fluence rate as it propagates through the CAT.

In discussing the optical properties of the coronary artery, it is important to distinguish between the fundamental optical properties and the transport properties used in the modelling work [18] as listed in Tables 2.1 and 2.2.

Table 2.1 Fundamental properties of tissue

Quantity	Symbol	Unit
Refractive index	η	dimensionless
Scattering coefficient	μ_s	cm^{-1}
Absorption coefficient	μ_a	cm^{-1}
Anisotropy of scatter	g	dimensionless

Table 2.2 Transport properties of tissue

Quantity	Symbol	Unit
Reduced scattering coefficient	$\mu'_s = (1\text{-}g)\ \mu_s$	cm^{-1}
Transport Mean Free Path (MFP)	MPF = 1/ $\mu_{a} + \mu_s$	cm

According to Vo-Dinh [19], the three photo-physical properties (refraction, scattering and absorption) are important to describe the propagation of light in biological tissue; and only the absorption coefficient, scattering coefficient, and reduced scattering coefficient are recommended for the measurement of the critical parameters for an optimal treatment of the coronary artery.

The following paragraphs will explain the critical parameters involved in laser treatment of heart disease.

According to Welch [20], the fluence rate is defined as the rate of energy delivered per unit area at a specific position. It is expressed in W/cm^2 and is determined by the optical properties of the tissue. In order to provide the correct laser irradiance dose (J/cm^2), it is advisable to determine the fluence rate reaching a required depth into the CA.

The beam profile affects the effective area or diameter of the laser beam [21]. The initial laser power is the power measured as emitted by the laser.

The absorption of a tissue is defined as the ability of the tissue to absorb the photons. It is expressed in cm^{-1}, which is not an SI unit but practical unit. Mathematically, it is defined as follows: $\mu_a = \rho_a \sigma_a$ where ρ_a is the volume density of chromophores contained in the tissue; and σ_a is an effective cross-sectional area [22], [23]. Scattering in tissue is generally caused by morphological variations in the tissue density and the refractive index [23]. It is mathematically expressed as $\mu_s = \rho_s \sigma_s$, where ρ_s and σ_s are respectively the volume density and effective cross-sectional area of scatterers [22], [23]. The last critical parameter for optimal laser treatment named ‘treatment duration’ is defined as the time that laser is on (applied) during the treatment.

3. Measurement methods of the critical parameters for optimal laser treatment of heart disease

In this section, the main focus of this paper is briefly shown, that is the theory and results that are based on the measurement or calculation of the required six critical parameters for an optimal laser treatment. Currently, there are more than three hundred thousand types of laser on the market [21]. Not all of them can be unusable for CA treatment. Therefore, the initial power and beam profile are important criteria in the choice of those that can be used to achieve the goal

3.1. Initial laser power measurement

Here, the authors advise the use of a calibrated power meter to determine the initial power of the laser.

3.2. Laser beam profile measurement

According to Stratan [21], charge-coupled device camera-based beam profilers can be used as a method to measure the diameter of the laser beam. The challenge in this method is the presence of two factors: the background noise and the integration area selected in the software, which affect the accuracy of the measurement. Using MATLAB, these two challenges can be evaluated and reduced. The diameter of the atherosclerotic tissue can also be measured using the routine technology method named coronary angiography, which is a procedure performed to view the inside of the vessels after injecting them with a radiopaque dye that outlines them on x-rays [24]. This method is considered an 'indirect method' because the measured organ's diameter is not that of the atherosclerotic substance that blocks the artery's lumen but the interior diameter of the artery. From several experiments done at the Council for Scientific and Industrial Research (CSIR), the laser beam profile diameter must logically be lightly smaller or equal to the diameter of the atherosclerotic tissue.

Using the correct laser beam profile diameter is important. The non-atherosclerotic cells will be damaged when the laser beam is bigger than the atherosclerotic substance. The treatment will take more time when its diameter is smaller than that of the blockage.

3.3. Fluence rate determination

In vivo, measurements to determine the fluence rate are seldom practical [25]. A computer modelling has capability to predict the fluence rate at any level into the CA tissue once the optical properties of the target treatment tissue are introduced [26]. This prediction of the fluence rate with a computer modelling is done by tailoring the properties of laser to the properties of the tissue.

3.4. Treatment time measurement

Treatment time is calculated mathematically using the thermal relaxation of the tissue being treated [27]. It is determined through the thermal relaxation time (time after which the heated tissue has capability to drop half of its heat) of the tissue under consideration. This thermal relaxation time (TRT) depends on the diameter of the tissue to be treated. Using an integrating sphere experimental technique, the values of the optimal properties of the CAT can be determined. With these values, the TRT will be calculated by using the layered computer model.

3.5. Absorption and scattering coefficient measurement

One of the following methods can be used to measure the important recommended optical properties for the coronary artery treatment: optical coherence topography or integrating sphere. Figure 1 shows the integrating sphere method used by the authors in December 2015.

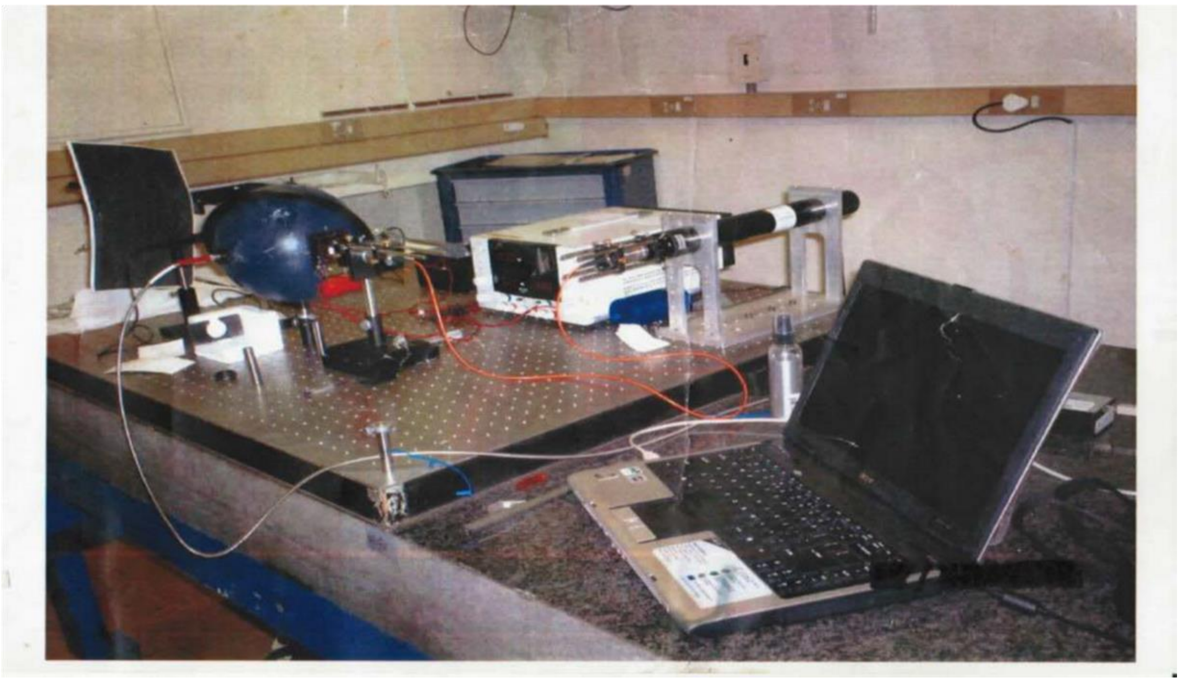

Figure 1. Measurement of the optical properties of a coronary artery using a computer package (December 2015).

4. Conclusion

As heart disease is the principal cause of death worldwide [28], and its treatment requires more attention, the authors have presented the critical parameters that must be considered when laser treatment is recommended for a patient. They have also presented different estimated methods to use for their measurements. Therefore, the authors believe that the correct measurement of the optical properties (absorption, scattering) of the coronary artery tissue and the six parameters estimated critical for the treatment are critical for optimal heart treatment. Another vital component to achieve optimal heart treatment is the application or administration of all the results from measurements to patients.

Due to a lack of data available on the absorption and scattering coefficients for CAT, different prototypes of CAT and of any atherosclerotic substance can be prepared in order to standardise and validate the technology. This means that the phantoms' optical properties must be predictable and adjustable to represent different layers of the CA and atherosclerotic substance. According to Dhanaliwala [29], the standardization requires phantoms that mimic actual tissue optical properties with a biological contrast agent, and are durable in order to serve as a reference to compare systems over time, and possess elastic properties similar to that of arteries.

For this reason, the authors of this article advise to fabricate the phantoms with the intravascular optical coherence tomography method (IV OCT) because this method is acknowledged for clinical use in different developed countries such as United States and Japan, as well as continents like Europe [6]. Different types of artery phantoms have been previously developed and presented by some researchers [8]. To present the optical and physical properties of the three layers (intima, media and adventitia) of the coronary artery, the authors advise to use the same support chemical material used previously by the researchers cited above for the responding phantoms. The chemical materials advised to be used include silicone (Sylgard 184, Dow Corning) and pure poly (polydimethyl siloxane) (PDMS) (Fluid 200, 50 CST, Dow Corning).

The computer model results must be compared favourably with laser measurements performed on the CA. These results from the computer model depend on both the accuracy of the model and the accuracy of the input data (optical properties). If the data on absorption coefficient for different prototypes is not readily available, it will necessitate the development of a diffuse reflectance probe system, which can be used to measure the absorption coefficient of the CA *in vivo*.

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