

Optical design of a variable angle irradiation system for skin cancer laser phototherapy

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Abstract. Photothermal therapy is a developing therapeutic technic mainly regarding the usage of nanoparticles considering their proneness to assemble around malignant tissue and induce their destruction by converting electromagnetic radiation into thermal radiation. In order to optimize this process, controlling the area of incidence in a way that it can fit the tumour and prevent damage of healthy cells is of great importance. This study was conducted by designing an optical system based on zoom systems for manipulating an initial input beam and adjust it to the most common skin cancer sizes. Two solutions are proposed, accomplishing spot sizes at 150 mm from the last lens within the approximate range of 2 mm to 76 mm, with beam divergences lower than 3 mrad.

1 Introduction

Photothermal therapy (PTT) is a minimally invasive therapeutic that can be used for cancer treatment. Recent advances using laser radiation have introduced nanoparticles as a solution to increase the volume of the affected malignant tissue and reduce damaging adjacent healthy cells [1]. In particular, the use of the surface plasmon resonance (SPR) effect by functionalized nanoparticles bounded to the tumour allows to maximize the conversion of laser radiation into thermal energy [2].

However, even considering that the SPR effect minimizes the interaction with healthy cells (where there are no nanoparticles) to reduce the energy being applied and thus minimizing costs, adjusting the laser beam on the tumour should be important. In general, lasers used in the considered PTT technique emit in the near-infrared and their beam is delivered by an optical fibre, which means having a divergent beam. Thus, the irradiation area can be adapted to the tumour size just by adjusting the distance. However, and considering the possible sizes of tumours, this solution is somehow limited.

Regarding more superficial tumours, such as those derived from skin cancer, they are commonly categorized into two types: melanoma and non-melanoma skin cancer. Non-melanoma skin cancer main forms are basal cell carcinoma characterized by an average diameter of 12.2 mm, ranging from 2.0 to 53.0 mm [3] and squamous cell carcinoma with an average tumour size of $24.9 \times 20.3 \text{ mm}^2$ [4]. Accordingly with [5], melanomas can be characterized by an average diameter of 14.4 mm, ranging from 2.0 to 76.0 mm. Thus, we established the goal of designing an optical system capable of dynamically manipulate the size of the laser beam to the size of the

tumour in the range 2 mm to 76 mm, keeping the distance of system to the tumour constant.

2 Methodologies

The starting point for the considered design was that of a simple zoom lens [6], a mechanical assembly of optical elements (lenses) for which the angle of irradiance (and focal length) can be varied. One of its most basic assemblies consists in having two positive lenses with the same focal lengths and one negative in the middle with a focal length, in absolute value, of less than half that of that of the positive lenses. **Figure 1** shows a schematic of this principle as implemented in this study, illustrating the main parameters to be considered: the input (D_i) and output (D_o) beam diameters, the distance between lens vertices (t_1 for L_1-L_2 , and t_2 for L_2-L_3), t the total length of the system, and d the distance from the last lens to the plane of irradiation. Although the designs of professional zoom systems are typically more complex, our application does not require complete collimation over all the range of output beam sizes and some divergence/convergence was considered acceptable. Nevertheless, the lowest divergence was always pursued.

ZemaxTM optical design software was used, and it was first assumed the design of custom-made lenses, and after the use of catalogue lenses to have a cheaper solution.

The input beam was assumed as collimated and having 50 mm diameter, a solution achievable using a collimator associated to the output of the fibre delivery system of a diode laser. The wavelength of the radiation was 808 nm and the distance between the output lens (L_3) and the tumour was fixed as 150 mm. The latter value was set based on our experience with *in vivo* animal testing.

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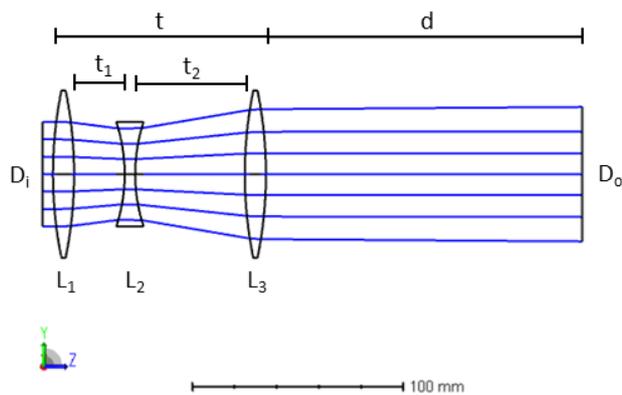


Fig. 1. Schematic of the basic zoom lens system considered in this work.

3 Results and analysis

The study revealed two solutions considered to solve the problem, following the principle mentioned before and using Zemax™ design tools, and **Table 1** resumes their performance.

The first system was designed with three custom-made lenses. The focal length of the positive lenses (80 mm diameter) was 195.85 mm and that of the negative lens (50 mm diameter) -78.34 mm. At the irradiation plane, D_o ranged from 1.7 mm to 75.4 mm by changing t_1 and t_2 . The corresponding values can be shown in **Figure 2**.

Table 1. Main parameters of the designed systems.
 (*Maximum divergence at the range where t is constant)

System	D_o (mm)	t (mm)	Max. divergence* (mrad)
Custom-made	1.7 to 75.4	101 to 154	1.4
Catalogue	1.8 to 87.5	114 to 134	3.0

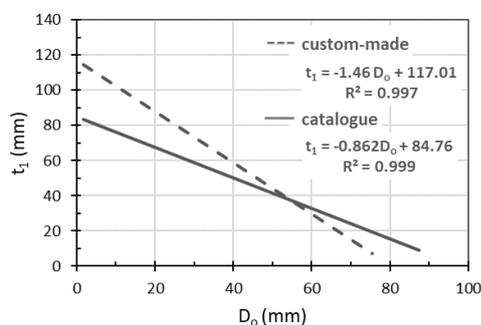


Fig. 2. Relation between the output beam diameter (D_o) and t_1 . t_2 changes are ruled by: (1) custom-made version - if $t_1 \geq 64$ mm ($D_o \leq 34.5$ mm) then $t_2 = 12$ mm, or else $t_2 = 76 - t_1$; (2) catalogue version - if $t_1 \geq 65$ mm ($D_o \leq 22.0$ mm) then $t_2 = 10$ mm, or else $t_2 = 75 - t_1$.

Following the first design, a more cost-efficient approach was followed resorting to catalogue lenses. The solution was obtained using two L-BCX269 (Ross Optical) positive lenses (150.60 mm focal length and 85.50 mm diameter) and a 017-0425 (OptoSigma)

negative lens (-59.54 mm focal length and 45.72 mm diameter). With this design the values of D_o can be made to change between 1.81 mm and 87.52 (**Figure 2**) but having higher values of maximal divergence (**Table 1**).

Other relevant parameter is the total system length, t . The chosen lenses were characterized by its small $f/\#$ which allowed to obtain reduced total system lengths (**Table 1**) to facilitate future clinical implementation. Therefore, by manufacturing limitations, the diameter of the negative lenses (both solutions) is smaller than that of the positive ones. Another different aspect from traditional zoom lens systems is the maintenance of a constant value t for a certain range. Outside this range, only t_1 changes (increase), and the beam starts to converge. This situation only occurs if one needs smaller spots, that is, when targeting smaller tumours.

4 Conclusions

Two solutions were proposed where a zoom-type lens system can dynamically change its output beam diameter according to the most common sizes of skin cancer. They were designed targeting smaller divergence values, shorter total system lengths and simpler future mechanical design.

None of the designs completely satisfy all the targeted parameters, in particular the low collimation along all the zoom range, and the total length of the system will be affected by the laser beam expander that was not included in this study. Nevertheless, these results point to a simple solution that can dynamically help laser phototherapy mediated by functionalized nanoparticles.

Future work will consist in testing the designs using laboratorial setups and in the development of a prototype for animal *in vivo* tests.

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