Modeling of light propagation in canine gingiva

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ABSTRACT

This study is a preliminary evaluation of the effectivenes of laser-based surgery of maxillary and mandibular bone in dogs. Current methods of gingivial surgery in dogs require the use of general anaesthesia.[1,2] The proposed methods of laser surgery can be performed on conscious dogs, which substantially reduces the associated risks.

Two choices of lasers, Nd:YAG and a 930 nm semiconductor lasers were evaluated. The former is already widely used in human laser surgery, while the latter provides an opportunity of decreasing the size of the optical setup.

The results obtained from the simulations warrant further experiments with the evaluated wavelengths and animal tissue samples.

Keywords: canine, dog, gingiva, laser, modeling, simulation, monte carlo

1. INTRODUCTION

Based on the experience from human medicine,[3] laser surgery is conjectured to pose fewer health risks than currently used, more invasive methods. While more detailed measurements of the optical properties of canine tissues are necessary to develop tissue phantoms suitable for experiments,[4–7] it is assumed that the optical properties of human tissues which are substantially documented in the literature are of sufficient similarity for a preliminary simulation study.

A simplified model of canine gingiva together with the underlying bone was developed, and its interaction with two types of laser beams was simulated. One of the examined lasers is the Nd:YAG laser commonly used in human medicine, while the other is a proposed 930 nm laser.

2. MODELING AND SIMULATION

2.1 Model of the canine gingiva

For the purpose of this study, the structure of the animal gingiva was assumed to comprise a planar layer of mucous tissue and an infinite layer of bone. The soft tissues (epitheleum and subepithelial connective tissue) of the gingiva were modeled as homogenous medium due to the low thickness of the epithelial layer, and the tissues below the bone layer were not modeled due to presumed low penetration of radiation into these tissues. A cross section of canine tooth and gingival tissues is shown in the fig. 1.

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12th Conference on Integrated Optics: Sensors, Sensing Structures, and Methods, edited by Przemyslaw Struk, Tadeusz Pustelny, Proc. of SPIE Vol. 10455, 104550H · © 2017 SPIE
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2281987

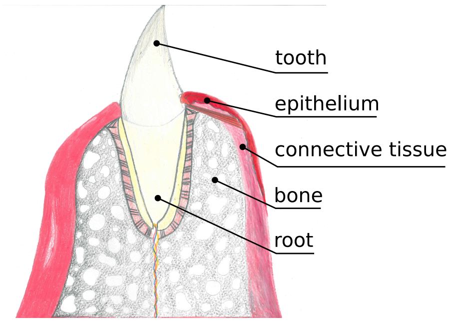

Figure 1. Cross section of a canine tooth and gingival tissues. The epitheleum and subepithelial connective tissue were modeled as a homogenous medium due to the low thickness of the epithelial layer. Author: M.Szczerska.

The depth of the mucous layer was assumed to be 1.7 mm, as per Kyllar et al.[11] Due to the lack of data pertaining the optical properties of canine tissues, the refractive index, reduced scattering coefficient, and absorption coefficient, were assumed to be similar to the values found for human tissues. This assumption is based on the fact that haemoglobin concentration, an important factor for a prediction of optical properties of biological tissues,[8] in human and canine gingiva is similar; the average Hb index in the gingival mucosa of healthy dogs cited is 0.217,[9] while the value for the mucosa comprising the attached gingiva in humans is cited as 0.212.[10] While further study is required to assess the accuracy of this approximation, it was considered acceptable for rough prediction of optical properties of canine tissues for the purpose of simulation.

The refractive index of mucosa was assumed as per Feldchtein et al.,[12] the scattering and absorption coefficients as per Bashkatov et al.,[13] and the scattering and absorption coefficients of cranial bone as per Bashkatov et al.[14] The collected data for mucosa is presented in table 1, and the data for cranial bone is presented in table 2.

Table 1. Optical properties of mucous tissue

	930 nm	1064 nm
Refractive index	1.4	1.4
Reduced scattering coefficient [1/cm]	6.89	5.54
Absorption coefficient [1/cm]	0.14	0.14

Table 2. Optical properties of bone

	930 nm	1064 nm
Refractive index	1.5	1.5
Reduced scattering coefficient [1/cm]	17.11	17.86
Absorption coefficient [1/cm]	0.22	0.16

Light propagation inside the modeled tissues was simulated using the Monte Carlo method, with the *mcml* program developed by Wang et al.[15] The results were convolved with Gaussian beams of $1/e^2$ width of 0.25 mm, 0.5 mm, 0.75 mm, and 1 mm, in order to obtain plots of absorbed power density in a function of depth z and distance from the beam center r. Slices of the results for the beam center $r = 0$ mm were also considered. Since the considered media are assumed to be optically linear, the input power was fixed as 1 W, unless otherwise noted. Results for different beam powers can be obtained by appropriate scaling.

2.2 Simulation results

The simulated absorbed power densities plotted against the depth and distance from the beam center are shown in the fig. 2. The results show that the 930 nm laser results in a narrower beam inside the mucous tissue than the 1064 nm Nd:YAG laser. Moreover, while using a narrower beam of the same total power results in higher power density, this also causes relatively more energy to be deposited in the mucosal layer. This can be seen in the plots in the fig. 3. For the same input power, the tissues illuminated by the Nd:YAG laser absorb less power than if the 930 nm laser was used. This result is shown in the fig. 4. If the input power is adjusted to result in approximately the same power absorbed at the surface of the bone layer (the required factor was found to be approximately equal to 1.23), using the Nd:YAG laser results in more power being absorbed in the mucosa.

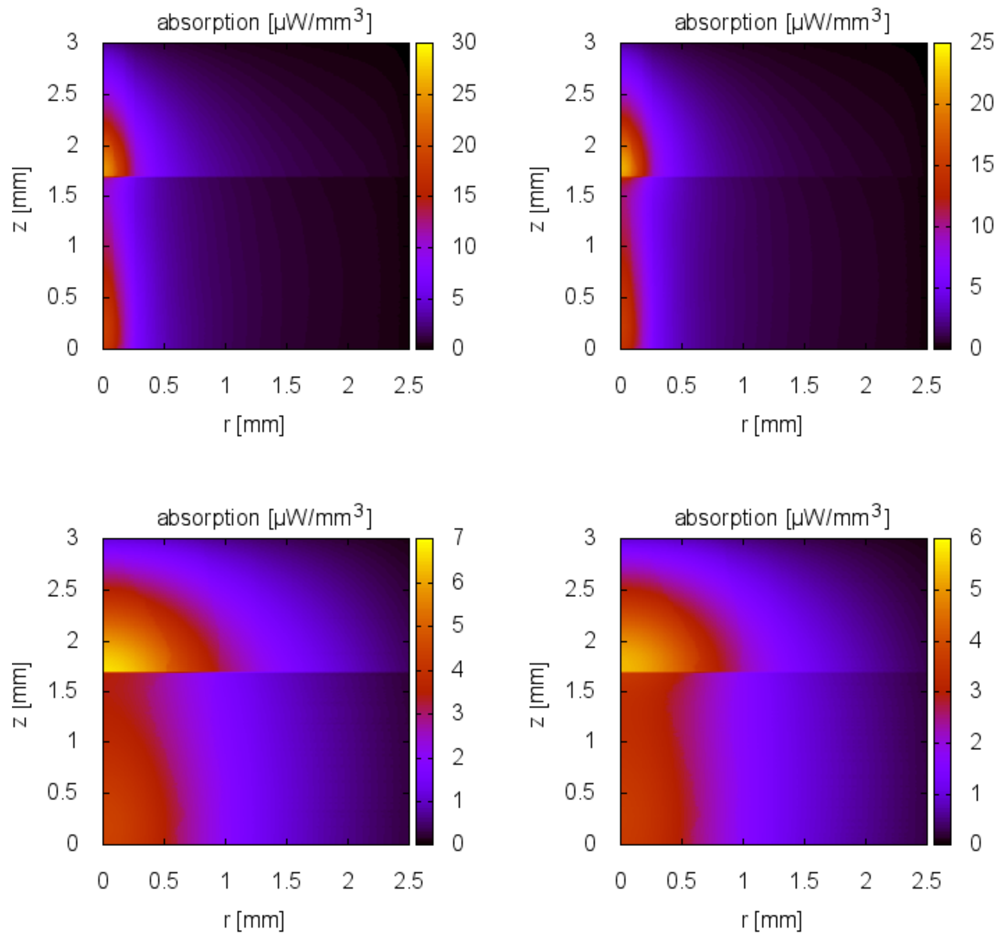

Figure 2. Radiation absorption as a function of depth z and distance from the beam center r, clockwise from top left: 930 nm laser, 0.25 mm beam, Nd:YAG laser, 0.25 mm beam, 930 nm laser, 1 mm beam, Nd:YAG laser, 1 mm beam.

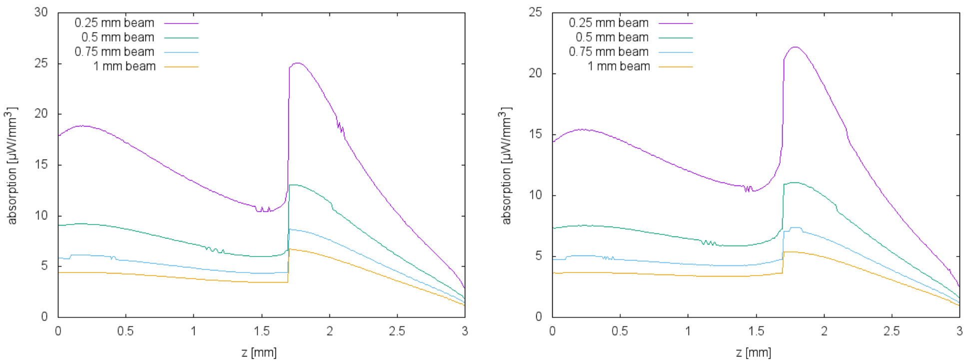

Figure 3. Comparison of radiation absorption as a function of depth for different beam widths, for (left) 930 nm laser and (right) Nd:YAG laser.

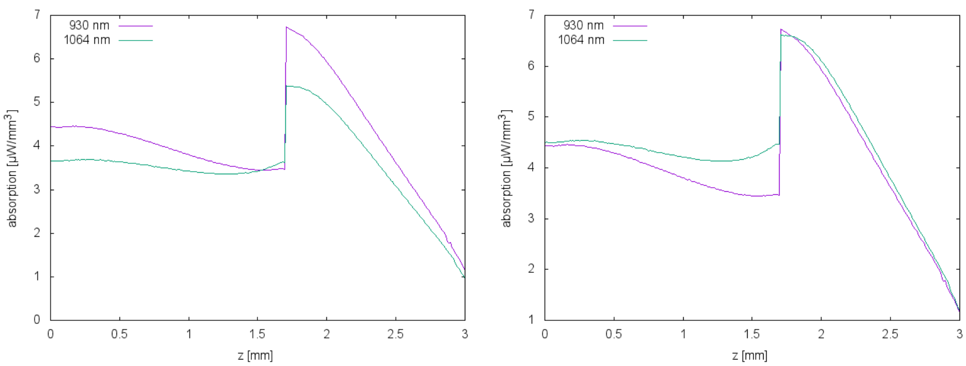

Figure 4. Comparision of radiation absorption as a function of depth for different laser types, for (left) constant input power, and (right) input power adjusted for the same power absorbed at the bone surface.

3. DISCUSSION AND CONCLUSION

The simulation results for both of the evaluated lasers are promising for the purpose of laser surgery of the maxillary and mandibular bone, with substantially more radiation absorbed by the bone tissue than the muscous tissue.

It has been determined that the proposed 930 nm semiconductor laser is more effective at delivering radiation to the underlying bone than the Nd:YAG laser. Together with the smaller size of the optical setup needed for semiconductor lasers than the Nd:YAG laser, this result points towards the potential usage of 930 nm lasers in veterinary medicine.

As an example, in order to deliver 6 W of absorbed power to the bone by using a Nd:YAG laser, as used as a component of combined Nd:YAG – CO2 laser system used by Arcoria et al.,[16] 4.875 W of power would be deposited in the mucous tissue, whereas a 930 nm laser would deposit only 3.8 W.

Further study, involving measurement of optical properties of animal tissues, the power and energy density required for 930 nm wavelength, and the nature of interaction of this wavelength with biological tissue is warrented.

4. ACKNOWLEDGEMENTS

This study was partially supported by the DS Programs of the Faculty of Electronics, Telecommunications and Informatics, Gdańsk University of Technology as well as by KNOW (Leading National Research Centre) Scientific Consortium "Healthy Animal - Safe Food", decision of Ministry of Science and Higher Education No. 05-1/KNOW2/2015.

The author would like to thank Veterinary Doctor Michał Wąsowicz from Department of Morphological Sciences, Faculty of Veterinary Medicine, Warsaw University of Life Sciences, Warszawa, Poland for consulting the modeling results.

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