

Optical-Thermal Simulation of Human Tonsillar Tissue Irradiation: Clinical Implications

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Background and Objective: Mucosa intact laser tonsillar ablation is an alternative to conventional tonsillectomy. The efficacy of this procedure was demonstrated in canines, but establishing the safety of irradiating human tonsils is paramount.

Study Design/Materials and Methods: An optical-thermal simulation of tonsillar tissue irradiation was previously developed, but the effect of varying parameters was not investigated. The tissue response to irradiation at 5–25 watts for 1 minute and 10 watts for 10 seconds to 162 seconds is simulated.

Results: At 15 watts and greater, the peak temperature is over 100°C and the mucosal temperature is over 70°C. At the depth of the tonsil, the temperature does not vary significantly. The peak temperature is at 1 mm. The radial temperature profile is not significantly altered by longer irradiation times.

Conclusions: The optimal dosimetry parameters for irradiation of human tonsillar tissue at 805 nm with the MILTA technique is under 15 watts for approximately 1 minute. *Lasers Surg. Med.* 27:269–273, 2000. © 2000 Wiley-Liss, Inc.

Key words: laser-tissue interactions; mucosa intact laser tonsillar ablation; optical properties

INTRODUCTION

Tonsillectomies are one of the most common pediatric operations performed annually. Despite the relatively high frequency of this procedure, there still remains morbidity and even mortality associated with this procedure. Researchers have attempted to lower the morbidity and mortality associated with tonsillectomies by introducing the laser as a surgical tool. A variety of laser systems have been developed for tonsillar procedures: CO₂ laser excision, interstitial photocoagulation, and mucosal intact ablation [1–3].

The mucosal intact laser tonsillar ablation (MILTA) procedure was developed to reduce the blood loss and the time to recovery associated with conventional tonsillectomies. In the MILTA procedure, the oral cavity is filled with saline and

the tonsil (under this fluid layer) is irradiated in a noncontact mode for 4 minutes. After approximately 6 weeks, histopathology examination [1–3] has revealed complete absence of tonsillar tissue in the irradiated area. The advantages of this procedure are noteworthy: no bleeding, a rapid operation, and quicker recovery than a conventional tonsillectomy [1,2].

The pilot studies performed with the Nd:YAG laser were successful in demonstrating the ablation of the tonsillar tissue [2]. The diode laser was proposed as an alternative to the

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Nd:YAG laser as the diode laser is a low-cost, portable, light-weight laser that offers the otolaryngologist the flexibility to use this surgical laser in the operating room or office settings [1]. In vivo canine studies with diode laser demonstrated ablation of the tonsillar tissue with similar results as the Nd:YAG laser [1].

A previous study by this laboratory characterized the underlying optical and thermal events during the laser irradiation of tonsillar tissue [4]. An optical-thermal simulation was developed to determine the response of human tonsillar tissue to the MILTA procedure [4]. The optical properties, a priori, demonstrated similarity between human and canine tonsillar tissue [4]. The simulation results confirmed this by demonstrating that the laser energy is contained within the tonsil in both canine and human models. This study also concluded that the diode laser is superior to the Nd:YAG laser for the MILTA procedure due to its more superficial effect, ensuring minimal collateral thermal damage to surrounding tissues and protecting the underlying vasculature at the base of the tonsil from thermal damage.

Simulation models offer the convenience and flexibility of evaluating a wide range of parameters (e.g., deposited energy, wavelength, duration of irradiation) for a desired outcome without the need for extensive in vivo trials. Once a desired outcome is approximated, the parameters can be further narrowed by a limited number of in vivo trials. Modelling applications result in a reduction of preclinical animal experiments, previously necessary to find an optimum dosimetry, and facilitate further refinement of existing procedures leading to safer and more efficacious laser applications.

In this study, the optical properties were used as inputs for an optical-thermal simulation program, which was used to predict the temperature rise in irradiated tissue. The validity of the model was corroborated by comparison with real-time temperature measurements obtained during in vitro canine tonsillar tissue undergoing irradiation [4]. Upon validation, the optical-thermal simulation was then used to predict the response of human tonsillar tissue to the MILTA irradiation parameters: 10 watts for 1-minute duration. In the present study, the effect of altering the total energy delivered was examined. The effect of irradiation of 5, 15, 20, and 25 watts was studied as was the effect of varying the duration of irradiation. The optical-thermal simulation allowed

definition of optimal irradiation parameters for the MILTA technique.

MATERIALS AND METHODS

Optical-Thermal Simulation

The optical-thermal simulation used in this study was developed by Dr. Nemati and Dr. Wang. The details can be found in Shah's work [4] and will not be repeated here.

Input Parameters to the Model

The optical simulation was carried out by using the measured optical properties of human tonsillar tissue for the diode laser wavelengths (805 nm) [4]. The refractive index of the tissue was assumed to be 1.37, and the anisotropy factor was fixed at 0.9. Each simulation was carried out for 1,000,000 photons. The thermal simulation was performed assuming a constant surface temperature of 37°C (normal body temperature), and a thermal transfer coefficient of 0.075 W/cm²°C [5]. The thermal conductivity of tissue was assumed to be 0.003 W/cm°C¹⁸, and the volumetric heat capacity was set at 3.7 J/cm³°C [5].

The power was simulated at 5, 15, 20, and 25 watts, while maintaining the duration of irradiation fixed at 1 minute. In the second simulation, the duration of irradiation was varied from 10 seconds to 162 seconds, while maintaining the power at 10 watts.

During the MILTA technique, the laser is moved in a "paintbrush" manner [1-3] over the surface of the tonsil in a noncontact mode. To attempt to simulate this novel approach, the simulation treated the laser irradiation of a discrete point on the surface of the tonsil as being irradiated in a pseudo-pulsed mode such that it was irradiated for 10 seconds and not irradiated for 1 second. Thus, during the 1 second when the point was not irradiated, we were able to obtain temperature measurements of the tissue without regard for the absorption of laser photons by the thermocouple [6]. To ensure consistency between the real-time measurements [4] and the simulation, the pseudo-pulsed mode of irradiation was used in this simulation.

RESULTS

The simulated response of human tonsil tissue to diode laser irradiation at varying powers is shown in Figure 1. At powers of 15 watts and

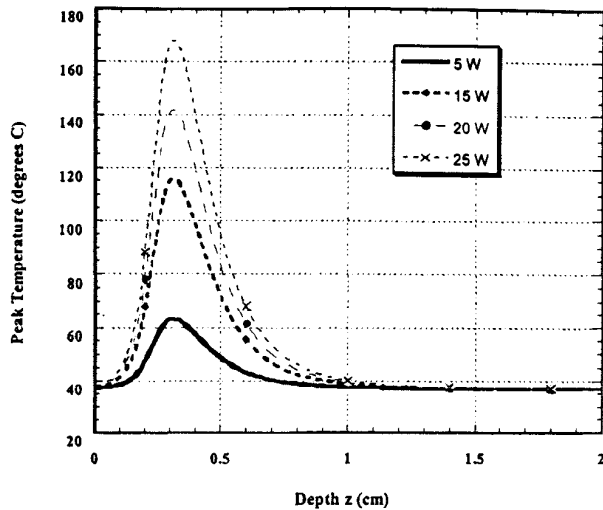


Fig. 1. Simulated depth-resolved peak temperature after diode laser irradiation of human tonsillar tissue for 1-minute duration.

greater, the peak temperature rise is over 100°C . Despite the varying peak temperatures at the different power settings, the temperature at the depth of the tonsil (approximately 8–10 mm) is not statistically different. Furthermore, the peak temperature is at a depth of 1 mm in the tissue at all power settings. Figure 3 demonstrates that the peak temperature is also at a depth of 1 mm in the tissue even when longer irradiation times are simulated. The surface layer of the tissue is at 2 mm in the graph as there is a 2-mm saline layer over the tissue [1–3]. At the surface layer, the power settings of 15 watts and greater cause a temperature increase of at least 70°C .

The repeated on-off cycle of the laser irradiation described in the Materials and Methods section as the pseudo-pulsed mode of irradiation (10 seconds on, 1 second off) establishes a temperature equilibrium (Fig. 2). As the duration of irradiation increases, the peak temperature for a point 1 mm below the tissue surface, directly under the beam, remains relatively constant (Fig. 3).

The thermal simulation of the radial spread of diode laser irradiation (Fig. 4) demonstrates that there is not much spread in the radial temperature profile as the duration of irradiation increases. Although there is a statistical difference between the first 10 seconds of irradiation and the longer durations of irradiation.

DISCUSSION

Despite the success of the MILTA procedure in *in vivo* canine studies, there have been con-

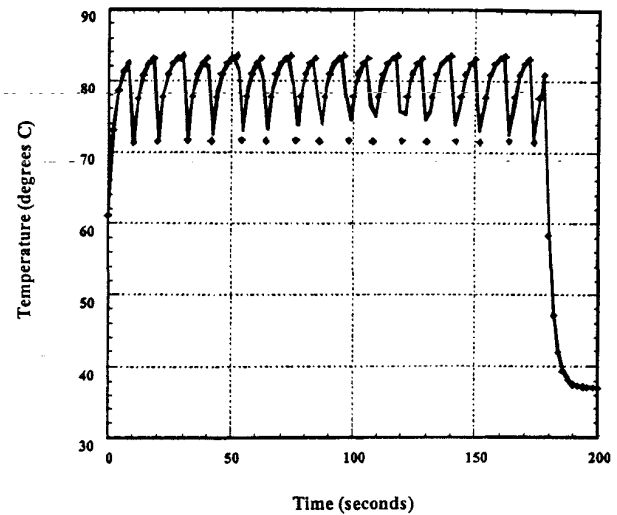


Fig. 2. Simulation of temperature response of tonsillar tissue 1-mm deep in the tissue ($z = 1$ mm) irradiated by diode at 10 watts.

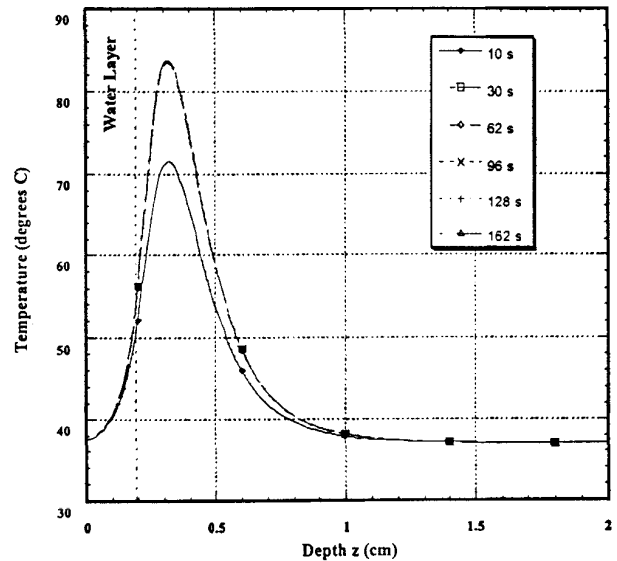


Fig. 3. Depth-resolved temperature response of human tonsillar tissue to diode laser irradiation.

cerns regarding the temperature elevation at the base of the tonsil. The temperature measurements and subsequent optical-thermal simulation described in an prior study [4] were performed to evaluate the temperature at the base of the tonsil during laser irradiation with the Nd:YAG and diode lasers. The *in vitro* canine tonsillar tissue results indicated that there was no significant difference in temperature rise at the base of the tonsil after laser irradiation at these two wave-

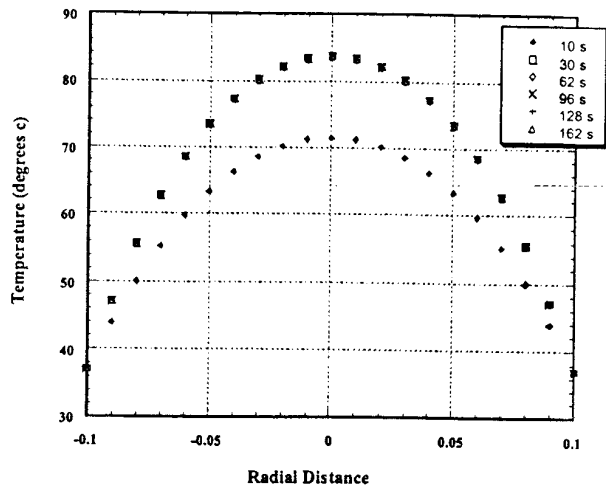


Fig. 4. Radial temperature response of human tonsillar tissue to diode laser irradiation at 1 mm below tissue surface.

lengths, suggesting that the heat is contained within the tonsillar tissue. The earlier study [4] only simulated a specific dosimetry: 1 minute of irradiation of 10 watts with the diode and Nd:YAG laser.

The present study examined the effect of changing the dosimetry on the thermal profile in the tonsillar tissue at the diode laser wavelength. The diode laser was chosen as the prior studies [3,4] established greater safety and efficacy with this wavelength.

The effect of varying the power between 5 and 25 watts resulted in a predictable increase in the peak temperature of the tonsil. Powers of 15 watts and greater would not be useful for the MILTA procedure for two reasons. First, the peak temperature at 15 watts is considerably over 100°C, which would certainly result in coagulative damage to the tonsil. Most authorities agree that above approximately 70°C, coagulation of tissue occurs. Second, at the higher powers of irradiation, the surface of the tonsil (2 mm depth in Fig. 1) has a significantly different temperature rise than at powers less than 15 watts. At powers of 15 watts and greater, the surface of the tonsil has a minimum temperature elevation of 70°C. This increase would presumably damage the surface layer of the tonsil, disrupting the mucosal surface and negating the beneficial effects of the MILTA technique: less pain and bleeding. Indeed, animal studies [3] demonstrated that at powers of 15 watts and greater, in vivo canine tonsils were becoming charred and, thus, damaged.

The effects of altering the duration of irradiation was studied in Figures 2–4. Prolonging the duration of irradiation does not increase the peak temperature in the tonsil because in the current delivery mode, given that a large volume of tissue serves as “heat sink,” the short off-times leads to rapid relaxation of tissue temperature, leading to an equilibrium in peak temperatures. However, tissue thermal damage is not just caused by peak temperatures, but also “time at the peak temperatures.” So for a longer duration of irradiation, the extent of thermal denaturation of tissue could be potentially higher and that can be established by histology rather than a simulation. The in vivo canine study did demonstrate that prolonging the duration of irradiation did result in greater areas of tissue damage and more importantly, disruption of the mucosal surface of the tonsil [3]. With shorter durations of irradiation (10 seconds), the radial temperature profile (Fig. 4) demonstrates that the laser does cause a significant increase in temperature at the longer durations of irradiation. As there is expected to be variability between each patient’s tonsils, the current pseudo-pulsed delivery mode provides a safety margin for the structures underlying the tonsil. If the surgeon decides one tonsil needs a longer duration of treatment than another, and the irradiation is 60 seconds in one tonsil and 90 seconds in the other tonsil, the data from Figure 3 demonstrates that the peak temperature will be the same in the tonsils.

The optical-thermal simulation previously reported [4] established the safety and efficacy of the MILTA procedure in human tonsillar tissue at the dosimetry regimens used in in vivo canine studies. The present study explored the response of human tonsillar tissue to diode laser irradiation at differing dosimetries. Increasing the power resulted in greater thermal rise in the tonsil and potential destruction of the mucosal surface of the tonsil. To preserve the mucosal surface and the intended benefits of the MILTA procedure, the power should be below 15 watts. Although with the current on-off cycling of laser irradiation a temperature equilibrium is established, it must be noted that the longer the tonsil is subjected to the peak temperature, the more damage will occur. It seems prudent to suggest the duration of irradiation to be approximately 60 seconds. Fortunately, slight variability in the duration of irradiation will not result in untoward complications to the structures underlying the tonsil. The optical-thermal simulation facilitated exploration of

various dosimetry regimens for the MILTA procedure, ultimately resulting in laser irradiation parameters that are anticipated to be safe and efficacious for use in irradiation of human tonsils.

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