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Arterial Pressure Responses of a Rat to Laser Stimulation of the Vagus Nerve Using Infrared Irradiation in Continuous-Wave Mode

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Abstract: Laser stimulation of the vagus nerve (VN) was successfully obtained using a 1505-nm diode laser in continuous-wave mode. Arterial pressure (AP) significantly decreased during the laser stimulation at the surface temperature of ~42 °C.

1. Introduction

The vagus nerve (VN) is the longest cranial nerve. The VN has a parasympathetic effect on systemic activities such as heart rate, arterial pressure, and respiration. Moreover, it can collect information from the autonomic nervous, cardiovascular, respiratory, gastrointestinal, immune and endocrine systems [1,2].

Infrared laser nerve stimulation (ILNS) is an emerging technique [3] that uses continuous-wave infrared laser energy to occur an action potential on a nerve without any extra modification or genetic manipulation. Infrared laser nerve stimulation has recently been explored in various neural tissue [4,5]. This relatively new technique may offer three main advantages over electrical nerve stimulation. (1) A non-contact method of nerve stimulation. (2) Improved spatial selectivity. (3) Elimination of stimulation artifacts.

In this report, we explored physiological responses of the sample to laser stimulation of the vagus nerve in a rat model, in vivo, including electrocardiogram (ECG) and a systemic arterial pressure (i.e., mean arterial pressure - MAP and pulsatile arterial pressure - PAP) recordings.

2. Methods

Figure 1 shows the experimental setup composed of AP measurements and the laser system. A pigtailed, single-mode, diode laser (BrightLock, QPC lasers, USA) was used for non-contact vagus nerve stimulation at 1505 nm in CW mode. A 660-nm diode laser with an optical power of 20 mW was used as an aiming beam to provide alignment. A single-mode fiber coupler (TN1310R1A2, Thorlabs, USA) with a 1:99 connection ratio combined both infrared and visible laser irradiation into a 0.5 mm diameter GRIN Lens. A thermal camera (Xi400, Optris GmbH, Germany) produced surface temperature mapping of the VN during laser stimulation.

Animal studies (a male Wistar rat model) were carried out under an animal protocol (protocol number: 04/2019) approved by Dokuz Eylul University Multidisciplinary Laboratory Animal Experiments Local Ethics Committee. Rat anesthetized with an intraperitoneal injection of 1200 mg/kg urethane. The rat was secured in a supine position on a surgical table. A four to five centimeters incision was applied to the far left of the trachea from the hyoid clavicles. Meanwhile, the trachea of the rat was cannulated to provide better respiration. The small cleft between sternomastoid and sternohyoid muscles was expanded using blunt dissection to identify the carotid artery and the VN located just behind the sternomastoid muscle. The left VN and carotid artery were separated from each other. The right carotid artery was isolated to measure systemic blood pressure [6]. The GRIN lens was aimed at the VN for CW-laser stimulation with the assistance of a red laser beam.

PE- 50 (Commat Ltd, Turkey) from intravenous cannula was used to measure systemic arterial pressure from the carotid artery. PE-50 intravenous cannula was connected to a pressure transducer (SS13L, Biopac Systems Inc., USA) with a three-way stopcock to measure arterial pressure. MP36 system with 1 kHz channel sampling rate, 1000X amplification, and DC high pass filtering was used to obtain AP signals obtain. The intravenous cannula and pressure transducer was filled with heparinized saline (100 IU/mL) to prevent clotting.

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The pressure transducer was calibrated before every experiment. Pulsatile arterial pressure (PAP) and mean arterial pressure (MAP) were also analyzed and calculated in BSL Analysis 4.1 (Biopac Systems Inc., USA) software.

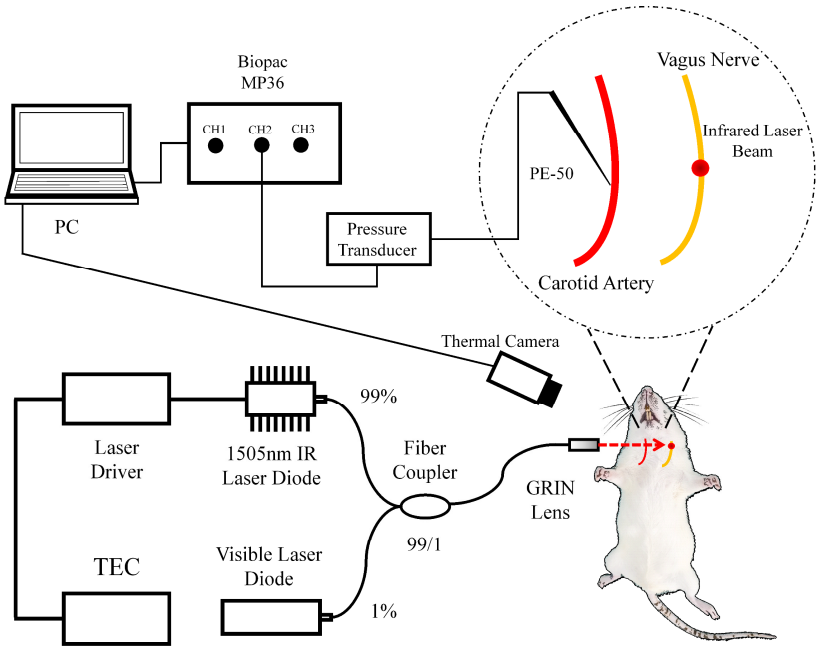

Fig. 1. A diagram of the experimental setup with CW-ILNS.

3. Results

Figure 2 shows representative MAP responses during CW-laser stimulation. The laser stimulation caused a significant decrease (17.04 mmHg) in MAP after about 3 s after laser irradiation began. 30 mW laser irradiation was elevating the VN above a threshold temperature of ~ 42 °C

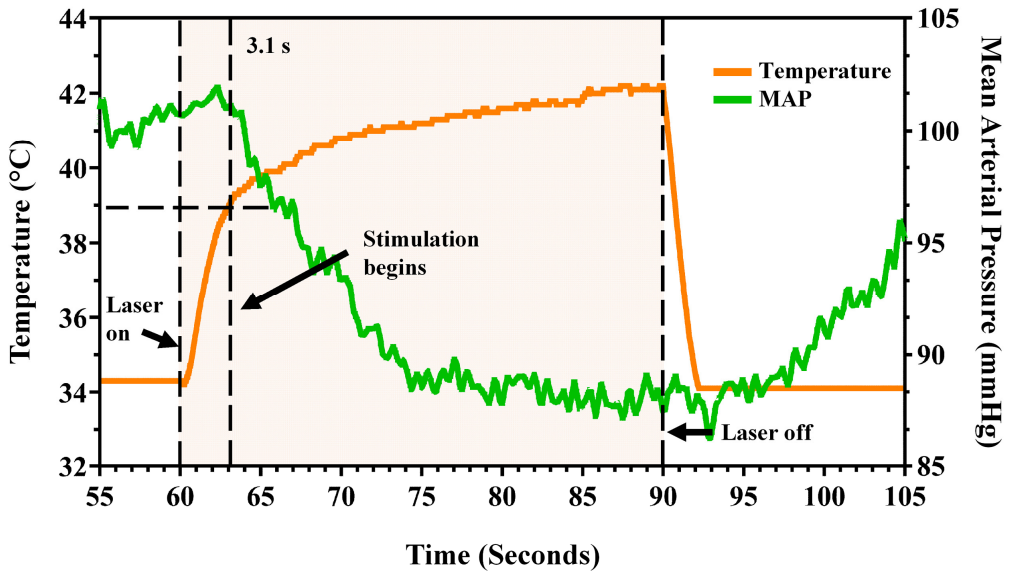

Fig. 2. A typical MAP response for CW-ILNS of the rat VN. Orange area indicates the stimulation period. Stimulation response time is about 3s.

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Infrared laser power was increased step by step until reaching determined temperatures to determine the stimulation threshold of CW-ILNS. As seen in Figure 3, the VN was irradiated until 41-41.9 °C and 42-42.9 °C temperatures with proper power. PAP and MAP did not change until 42° C significantly. After 42° C, a significant decrease was observed between 42-42.9 °C. VN was always controlled to achieve desired levels of temperature with a thermal camera.

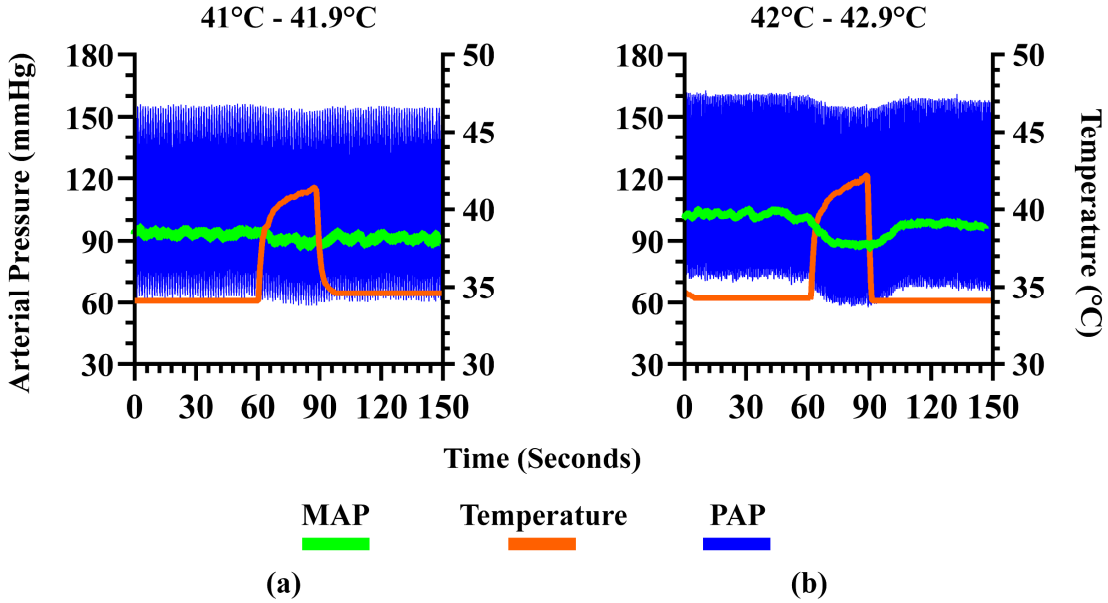

Fig. 3. Representative responses to CW-ILNS in terms of PAP and MAP at different levels of temperature (a) 41-41.9 C, (b) 42-42.9 C

4. Conclusion

In this report, we explored physiological responses of the sample to laser stimulation of the vagus nerve in a rat model, in vivo. The measurements included electrocardiogram (ECG) and a systemic arterial pressure (i.e., mean arterial pressure - MAP and pulsatile arterial pressure - PAP) recordings. We operated a 1505-nm diode laser in continuous-wave mode. A significant decreased in the MAP was obtained during the laser stimulation. The nerve reached a peak temperature of >42 °C, just above the nerve stimulation threshold.

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