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OCTA-guided Photo-mediated Ultrasound Therapy

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Abstract: We developed a high speed PUT system to achieve faster blood vessel destruction, decreasing the treatment time by a factor of 20. Furthermore, we integrated it with optical coherence tomography angiography for real time monitoring. The feasibility of the proposed OCTA-guided PUT was validated through in vivo rabbit experiments.

Port-Wine Stain (PWS) is characterized by ectatic capillaries and postcapillary venules located predominantly in the papillary and mid-reticular layers of the dermis [1]. Despite advancements in laser treatment, complete PWS resolution remains rare. It was reported that less than 20% PWS can be completely cleared [2] and approximately half of all PWS patients bear lesions that are recalcitrant to current treatment options [3]. Photo-mediated Ultrasound Therapy (PUT) [4-6], a new anti-vascular technique based on photospallation, applies nanosecond laser pulses and ultrasound bursts simultaneously to promote cavitation activity to destruct blood vessels. PUT is highly selective and provides a high-precision localized treatment because the cavitation will be limited to the blood vessels. Additionally, PUT can avoid unwanted damage to the surrounding tissues because it uses much lower energy, for both laser and ultrasound, than individually required by traditional laser treatments and traditional therapeutic ultrasound [7].

Optical coherence tomography angiography (OCTA) is capable of generating high-resolution tomographic images of vasculature and has been used as a real-time monitoring tool. It has had a growing impact in the field of dermatology over the last 10 years.

Here, we demonstrate the viability of an OCTA- guided PUT system. First, we greatly improved PUT by adopting a high-speed pulsed laser to achieve faster treatment, decreasing the treatment time by a factor of 20. Furthermore, we incorporated OCTA into PUT though a double-clad coupler for real-time monitoring of treatment response. In vivo rabbit experiments were performed to test the feasibility of this proposed technology.

The schematic diagram of the OCT-guided PUT system is shown in Figure 1. The DCF coupler is applied to combine OCT illumination and PUT laser pulses. OCT uses a 1310 nm Micro-Electro-Mechanical (MEMS)-tunable Vertical Cavity Surface Emitting Laser (VCSEL) swept source with a sweep rate of 100 kHz and a bandwidth of 100 nm. For PUT, a 1064-nm nanosecond laser with a repetition rate of up to 100 kHz is utilized. The output of the nanosecond laser is focused by a condenser lens into the multimode fiber (MMF). A function generator is used to synchronize the pulse/delay generator for pulsed laser emission as well as generating a sine wave used for ultrasound emission. The high intensity focused ultrasound (HIFU) transducer, coaxially aligned with the laser beam, is immersed in warm water (~37°C) for acoustic coupling.

We performed in vivo experiments on the ears of rabbits. OCTA was performed before and after PUT.

Figure 2 shows the representative OCTA images from the ears of rabbits. Figures 2(a) and 2(b) show a photo and OCTA image of the rabbit ear before PUT treatment, where the treatment area is labeled by white arrows. Figure 2(c) shows an OCTA image of the rabbit's ear after PUT treatment, where a blood vessel destruction can be clearly visualized as indicated by the white circle.

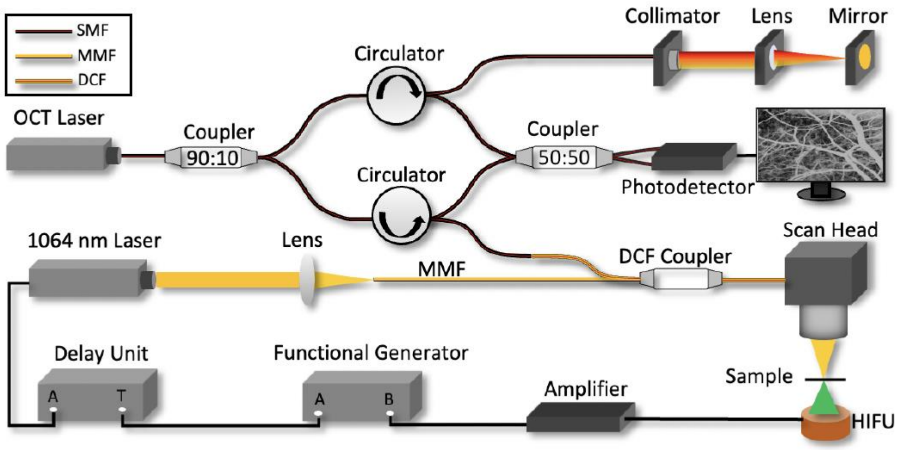

Figure 1 Schematic of OCT guided PUT system. DCF: double clad fiber. SMF: single mode fiber. DCF: double clad fiber. HIFU: high intensity focused ultrasound. MMF: multimode fiber.

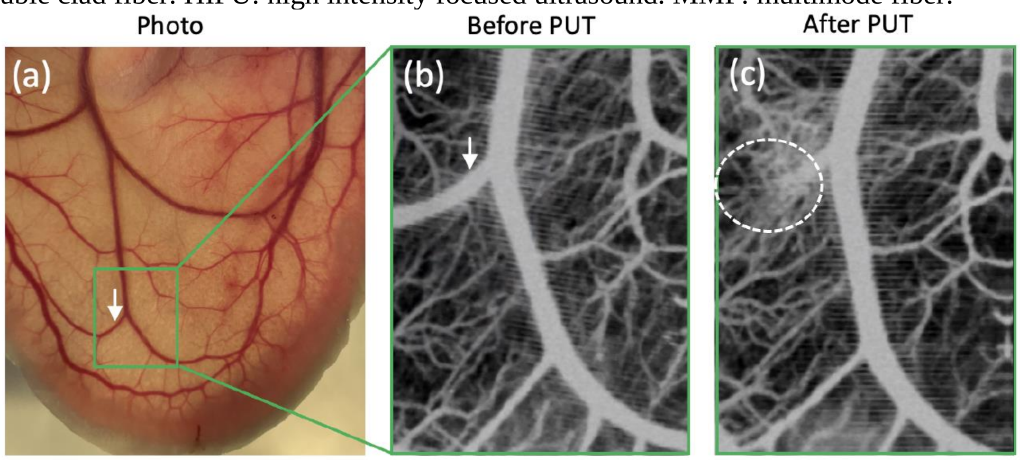

Figure 2 Photo and OCTA images of rabbit ear. (a) Photo of rabbit ear before and after PUT. (b) and (c) OCTA images before and after PUT.

Here, an OCTA guided PUT system was demonstrated and its feasibility was validated via in vivo rabbit experiments. Compared with the reported PUT systems [4-6], our PUT system features a high speed pulsed laser that can reduce the treatment time by a factor of 20. Furthermore, the addition of OCT provides a non-invasive diagnostic and monitoring tool, and has the potential to further improve the safety and efficiency of PUT.

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