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Clinical Embodiments of Laser Speckle Imaging for Real-Time Blood-Flow Monitoring

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Abstract: Laser Speckle Imaging (LSI) is used widely in preclinical studies of blood flow, especially in neurobiology. However, clinical application of LSI remains underexplored. Here, I describe our experiences in developing clinic-friendly embodiments of LSI.
OCIS codes: (170.1470) Blood or tissue constituent monitoring; (170.3890) Medical optics instrumentation; (030.6140) Speckle

1. Introduction

Stern [1] introduced the method of laser Doppler flowmetry to characterize tissue blood flow. Since this seminal publication, several research groups developed new optical methods to assess microvascular blood flow in tissue. Fercher and Briers [2] first proposed the analysis of laser speckle patterns to map blood flow in the retina. In its most basic form, Laser Speckle Imaging (LSI) involves acquisition of a snapshot picture of an object illuminated by laser light. The resultant picture contains a speckle pattern with a local speckle contrast that is related to the motion of optical scatterers, such as red blood cells. As the scatterers move, the local speckle pattern fluctuates. Typically, a camera exposure time is selected that is considerably longer than the speckle decorrelation time associated with this fluctuation, resulting in a local blurring of the pattern and hence a decrease in speckle contrast. Research groups previously published several methods to analyze the raw speckle images [3-5].

Despite the numerousadvances in speckle contrast analysis, LSI remains best suited for study of relative changes in blood flow in acute preparations with exposed blood vessels, such as imaging of the rodent brain in response to external stimuli [6] or the microvascular response to phototherapy [7]. An important consideration for laser speckle imaging is the constraint imposed by the target organ of interest. In general, clinical use of LSI remains restricted to exposed organs such as the skin. Here, I describe recent efforts focused on LSI device engineering to address application-specific demands.

2. LSI in the Operating Room

In the OR, the key demands include real-time visualization and a device footprint that does not interfere with ongoing surgical procedures. To this end, we developed a LSI system on a tripod that provides real-time visualization of blood flow (Fig. 1A) [8]. We used Graphics Processing Unit-based programming to achieve real-time processing of the raw speckle images [9]. We used this device to collect data from 24 subjects undergoing laser surgery of port-wine stain (PWS) birthmarks, with the goal of determining the correlation between PWS skin blood flow reduction (assessed during pulsed laser surgery) and clinical grading of treatment outcome (assessed four to six weeks after treatment) [Fig. 1(B-D)]. We determined that the degree of PWS blanching in response to laser surgery tends to increase with the magnitude of blood-flow reduction [(Fig. 1(E)]. Our data support our approach of intraoperative LSI to monitor treatment progress and ultimately as real-time feedback to advise regarding the need for immediate additional treatment to regions of persistent perfusion.

3. LSI within the body

To image within the body, the key engineering challenge includes delivery of laser light to the internal organ and acquisition of raw speckle images. We adopted fiber-based methods to deliver the laser light and to transmit images from the target to an external camera. To characterize pulpal blood flow of teeth, as a method to assess pulpal vitality and need for root canal surgery, we integrated a fiber optic with a custom retroreflector to deliver laser light to the lingual side of the tooth. We paired this with a second coherent fiber bundle containing ~10,000 individual fibers, that transmitted the speckle pattern from the buccal side of the tooth to an external custom-built microendoscope (Fig. 2).

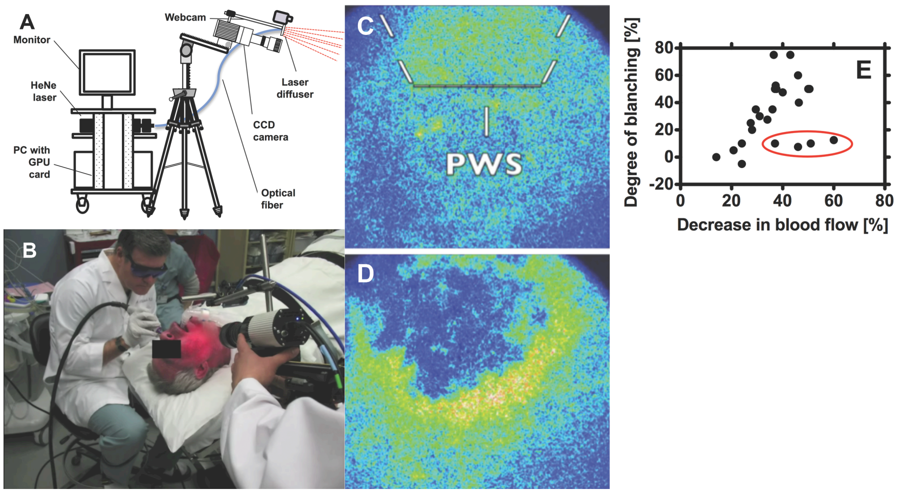

Fig. 1. Real-time LSI enables intraoperative assessment during pulsed laser surgery of PWS birthmarks. (A) Schematic of tripod-based LSI device. (B) LSI in clinic. (C,D) SFI images extracted from a real-time video feed taken (C) prior to and (D) after one pass of a 595-nm pulsed dye laser. (E) Summary of preliminary data (n = 24). We assessed degree of blanching with qualitative scoring of color photographs taken prior to laser and then at next treatment visit. We quantified the decrease in SFI from collected LSI data. Interestingly, four of the 24 subjects (data points within red oval) experienced minimal blanching of their PWS

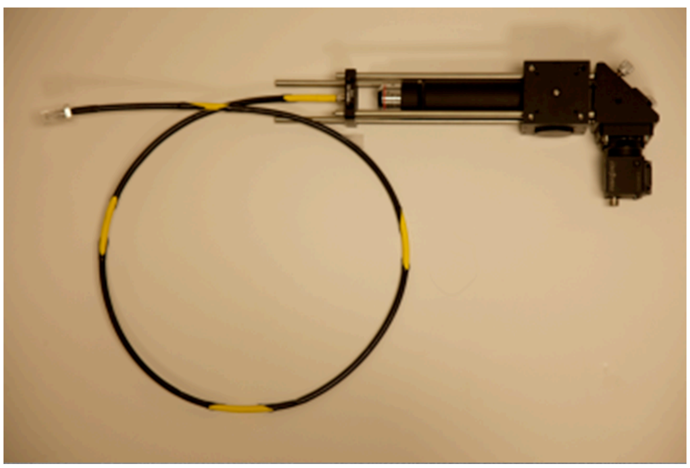

Fig. 2. LSI device based on use of a coherent fiber bundle, for imaging within the body.

4. Conclusions

LSI is a simple, cost-effective technology for use in preclinical studies. With careful consideration of the demands of each clinical application, I postulate that LSI can be readily integrated into form factors with widespread, routine use to furnish critical information to clinicians on tissue blood-flow dynamics.

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