

Biomedical Applications of Laser Speckle Imaging



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INTRODUCTION

Laser Speckle Imaging (LSI), developed by CW Optics, has applications in measuring blood flow velocities for various human physiological conditions. Data obtained from human studies in three advanced application areas are presented: (a) viability of transplanted tissue flaps, (b) retinal blood circulation, and (c) sublingual blood flow velocity measurements for monitoring sepsis. The LSI technology is patented under US 7113817.

BACKGROUND

When tissue is illuminated with a laser, dynamic speckles associated with the motion of red blood cells are observed [1], [2], [3]. The LSI technique uses a charge-coupled device (CCD) camera to capture the laser speckle pattern as shown in Fig. 1.

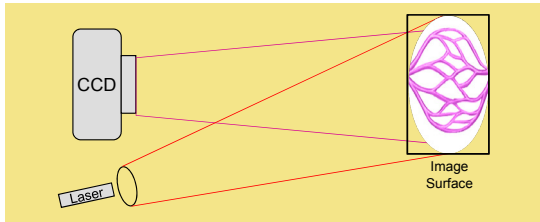


Fig. 1. Schematic diagram of the LSI setup. An expanded laser beam illuminates the area of interest. The observed speckle pattern is captured with a CCD camera.

Temporal variations of the speckle contrast at every point on the image are extracted from the acquired laser speckle pattern. Spatial distribution of the speckle image is obtained by computing the average intensity $I(x, y)$ and the speckle contrast $d(x, y)$ over a pre-defined neighborhood of a point (x, y) . The speckle contrast is defined by:

$$d(x, y) = \sigma(x, y) / \langle I(x, y) \rangle$$

where $\sigma(x, y)$ is the standard deviation of intensity over the pixel neighborhood. The speckle contrast values are related to blood flow velocity distribution [2]. Quantitative velocity values are obtained from a spatial analysis based on multiple scattering considerations.

TISSUE VIABILITY

In 2007, diabetes cost \$174 billion in the United States. Diabetics often have non-healing, lower extremity wounds, which require amputation 50% of the time when they are untreated. Monitoring tissue perfusion for patients during and after wound treatment, surgery involving flaps, transplants, and vascular reconstruction is important in order to ensure a successful outcome.

TISSUE VIABILITY (cont'd)

Clinical Study and Results

- 15 patients receiving free flap transfer [2]
- LSI and laser Doppler flowmetry (LDF) measurements after flap fixation in operating room and daily post-op
- LDF strongly affected by pigmentation, not LSI.
- Reproducibility >90% for LSI and approx. 20% for LDF

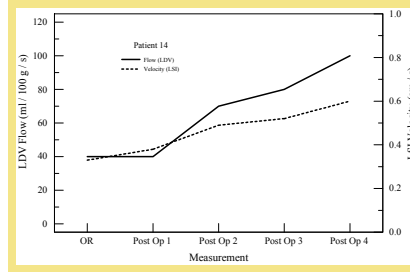


Fig. 2. Comparison of LSI velocity and LDF flow. A free radial forearm flap was grafted to the floor of the subject's mouth.

RETINAL BLOOD CIRCULATION

In the United States, 16 million diabetics are targets for retinal blinding disorders and another 13 million people show signs of macular degeneration. LSI provides quantitative blood velocity values that allow ophthalmologists to corroborate diagnoses, detect at-risk populations early, and follow disease processes through therapeutic intervention.

Clinical Study

- A modified fundus camera was used (Fig. 3).
- 30 adult subjects. [4]
- Speckle Images were obtained while the subject was breathing room air, and after the subject had breathed pure oxygen for 5 min.

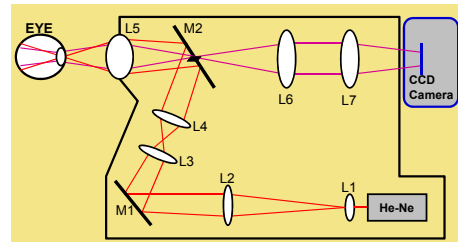


Fig. 3. Schematic diagram of the fundus camera.

Results

- No noticeable difference between genders.
- Pigmentation does not affect blood velocity.
- Retinal blood velocities decreased by 35% after 5 min of breathing 100% O₂ (Fig. 4).
- Blood velocities at large vessels and capillaries range from 0.5-1.2 cm/s and 0.04-0.1 cm/s, respectively, in agreement with literature.

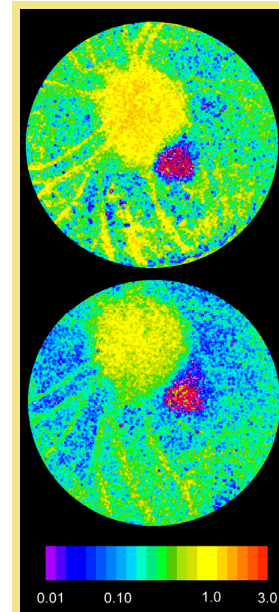


Fig. 4. Retinal blood velocity mappings, top: breathing room air, bottom: after 5 min. of breathing pure O₂.

SEPSIS

Sepsis affects more than 800,000 Americans and causes 250,000 deaths yearly at a cost of \$17 billion. CW Optics' LSI Scope provides quantitative sublingual blood velocity measurements for early detection of potentially septic patients.

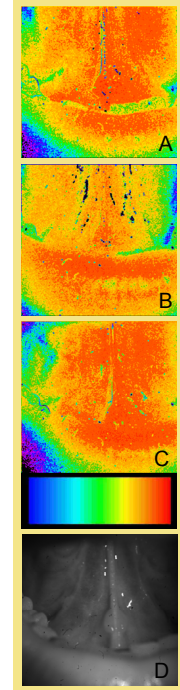
Human Study

- 20 healthy subjects. [5]
- Sublingual Area measured with LSI Scope at different temperatures.

Results

- Sublingual blood velocities range from 0.15 mm/s to 0.7 mm/s for normal, hot, and cold temperatures.
- Figure 5 shows a typical set of temperature-dependent velocity mappings, (A) 26°C, (B) 36°C, (C) 41°C.
- The increase of sublingual blood velocity at both hot and cold temperatures from that at normal temperature is observed for all 20 subjects. This effect is also observed in the LDF measurements of two subjects.
- The LSI Scope is currently being tested on ICU patients.

Fig. 5. Sublingual blood velocity mappings at cold (A), normal (B), and hot (C) temperatures. (D) shows an unprocessed image of the sublingual area.



CONCLUSIONS

The LSI technology is a powerful tool for monitoring microcirculatory conditions. It provides quantitative and reproducible measurements in realtime. CW Optics is exploring other potential application areas of LSI. A clinical study for monitoring the progression of chronic diabetic leg wounds is scheduled for early 2009. FDA 510(k) submissions are currently being prepared.

REFERENCES

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