Considerations for Intraoperative Laser Speckle Contrast Imaging for Vessel Flow Visualization

Alexis Dimanche
Dept. of Biomedical Engineering
The University of Texas at Austin
Austin, USA
alexis.dimanche@utexas.edu

David R. Miller
Dynamic Light, Inc
Austin, USA

Andrew K. Dunn
Dept. of Biomedical Engineering
The Univeristy of Texas at Austin
Austin, Texas

2023 IEEE Biomedical Circuits and Systems Conference (BioCAS) | 979-8-3503-0026-0/23/$31.00 ©2023 IEEE | DOI: 10.1109/BioCAS58349.2023.10388521

Abstract*— *Laser speckle contrast imaging (LSCI) has emerged as a promising non-invasive optical technique for assessing blood flow dynamics in clinical settings, including neurosurgery. This study aimed to illustrate the challenges and limitations associated with intraoperative LSCI-based blood flow assessment. A custom microscope-integrated LSCI device was utilized in 20 neurosurgical procedures, providing real-time high-resolution imaging. Two clinical observations were reported, highlighting the impact of static scattering and limited penetration depth on LSCI measurements. Calcified vessel walls affected the speckle contrast values, emphasizing the importance of precise thresholding for meaningful blood flow visualization and intraoperative display. Furthermore, LSCI demonstrated limited capability in assessing blood flow within thick vessels such as the carotid artery. The results shed light on the potential applications and limitations of LSCI in surgical interventions, emphasizing the need for further research. Overall, LSCI shows promise as a valuable tool for evaluating tissue perfusion and vessel flow, but careful consideration of its limitations is crucial for successful implementation in clinical practice.

Keywords— Laser speckle contrast imaging, blood flow imaging, neurosurgery, speckle contrast, aneurysm

I. INTRODUCTION

Laser speckle contrast imaging (LSCI) is a non-invasive optical technique that has gained significant attention in the field of clinical imaging for its ability to assess blood flow dynamics[1].The real-time and high-resolution imaging capabilities of LSCI make it a promising tool for evaluating tissue perfusion and vessel flow in clinical settings including neurosurgery [2]–[4]. One of the primary challenges faced by single exposure LSCI is the influence of static scattering on the measured speckle contrast (K) value [5]–[7]. In tissues with increased static scattering, such as those with calcified vessel walls, the K value can be affected. This limitation poses a significant concern when visualizing and displaying LSCI display blood flow maps intraoperatively. Indeed, there is a need for precise thresholding of K to ensure sensitivity to variations in blood flow.

Furthermore, another limitation of single exposure LSCI is its limited penetration depth [8]. The depth at which LSCI can effectively capture blood flow information is constrained by the optical properties of the tissue under investigation. In applications where deeper structures or thicker vessel walls are involved, the penetration depth of LSCI, limited to ~1mm [9] , may be insufficient to provide comprehensive assessment of blood flow dynamics.

The goal of this paper is to illustrate these challenges and investigate their impact intraoperatively. In this regard, the clinical observations reported in this paper are derived from a recent clinical trial where LSCI was used in 20 neurosurgical procedures. The results aim to enhance the accuracy and reliability of LSCI-based blood flow assessments during complex surgical interventions while furthering our understanding of the prospective clinical applications of LSCI.

II. MATERIALS AND METHODS

A. Study Design

This manuscript presents two observations imaged during a single-center prospective observational cohort study which included 20 patients undergoing various types of neurosurgeries. The study was conducted at the Inselspital Bern University Hospital in Bern, Switzerland (ClinicalTrials.gov identifier: NCT0502840) and approved by the local ethics committee (Project-ID: 2021-D0043). Informed consent was obtained from each patient prior to the neurosurgical procedure. Intraoperative LSCI was conducted without interrupting the surgical workflow.

B. Intraoperative Instrumentation

A custom microscope integrated LSCI device was utilized in this study as depicted in Fig. 1 [4]. The device was mounted onto the surgical microscope without interfering with its

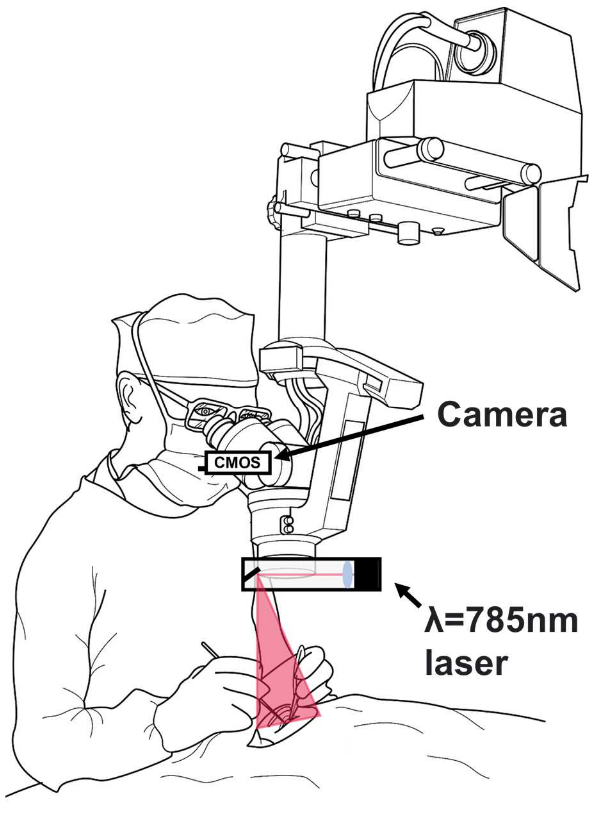

Fig. 1: LSCI intraoperative instrumentation attached to the operating surgical microscope.

Authorized licensed use limited to: University of Oklahoma Libraries. Downloaded on December 17,2025 at 21:45:13 UTC from IEEE Xplore. Restrictions apply.

normal use. Illumination of the surgical field of view was achieved using a λ=785 nm laser diode, with the laser irradiance maintained below 0.10 W/cm², well within safety limits [10]. The coherent light reflected back from the surgical field of view was collected through the microscope's imaging optics and captured by a camera mounted on the side observer port of the operating surgical microscope (Carl Zeiss Meditec AG, Oberkochen, Germany).

C. *Laser Speckle Contrast Imaging*

LSCI relies on the analysis of a speckle pattern. When a coherent light source such as a laser illuminates the area of interest, light is backscattered from the tissue and captured by a camera over an exposure time, T. The motion of light scattering particles in the tissue alters the interference pattern, causing blurring over the camera's exposure time. The raw speckle pattern is processed using a sliding window of 5x5 pixels to compute K at each pixel. K is calculated as the ratio of the standard deviation (σ) to the average intensity ($\langle I \rangle$) of the pixel values included in the window as shown in the following equation:

$$K = \sigma / \langle I \rangle \tag{1}$$

The speckle contrast values are inversely proportional to flow. High K values approaching 1 indicate an absence of blurring of speckle and therefore, no motion. In contrast, low K values approaching 0 indicate that the scattering particles (e.g.: red blood cells) are moving fast enough to blur all the speckles.

The camera images were processed in real-time using SpeckleView®, a custom software developed by Dynamic Light Inc. The software converted the camera image into LSCI images and displayed blood flow visualizations to the operating surgeons via the operating room monitors.

D. *Intraoperative Image Processing and Display*

During the surgery, the real-time display of LSCI images on the operating room monitors was achieved with the SpeckleView® software, which was controlled by a researcher responsible for adjusting the image display settings. The setting selection process is comprised of the following steps:

First, a colormap was assigned to the LSCI images to represent the range of K values. Next, a thresholding technique was employed to enhance the interpretability of the LSCI images. The K values were evaluated, and a specific range was defined to highlight the relevant flow information. Only the pixel values falling within this predefined range were mapped using the colors of the predefined colormap. This thresholding process aims to enhance the visual representation of areas of interest and minimize noise, resulting in a more accurate and meaningful visualization of blood flow variations.

III. Results and Discussion

A. *LSCI during a Calcified Aneurysm Procedure*

Fig. 2 shows LSCI blood flow measurements (T=1.9ms) of the surgical field of view during a calcified middle cerebral artery (MCA) aneurysm clipping procedure. The average K in the aneurysm sac region of interest (ROI 1) increased from 0.213 to 0.321 after positioning of the clip indicating a strong decrease in flow and successful clip placement. Furthermore, the average K values observed in the branching arteries (ROI 2 & 3) before and after the clip placement remained consistent (M=0.069, SD=0.006), indicating the sustained patency of these arteries as presented in Fig. 2(d). Thus, LSCI successfully measured the expected changes in blood flow during microsurgical clip placement.

Moreover, our results show that the preclipping LSCI blood flow measurements in the calcified aneurysm (ROI 1) are high relative to the branching vessels (ROI 2 & 3) where

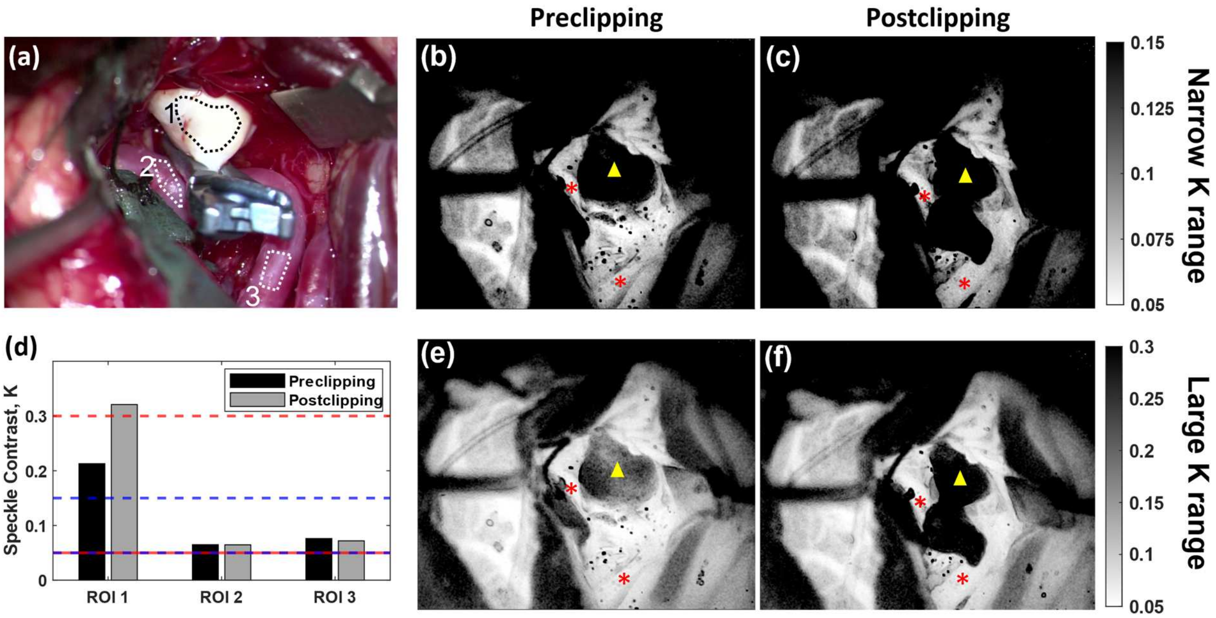

Fig. 2: (a) Magnified white light image of the surgical field of view depicting the numbered regions of interest (ROIs) used for analysis. ROI 1 represents the clipped calcified aneurysm sac and ROI 2 & 3 the branching M2 arteries. LSCI images of the surgical field with different speckle contrast (K) thresholding ranges preclipping (b), (e) and postclipping (c), (f). The aneurysm sac is visually indicated by a yellow triangle, whereas the branching arteries are represented by red asterisks. (d) Barplot comparing the SC values in the ROIs before and after clipping. The dotted lines represent the narrow range [0.05, 0.15] of displayed K values while the full lines represent the large range [0.05, 0.30].

Authorized licensed use limited to: University of Oklahoma Libraries. Downloaded on December 17,2025 at 21:45:13 UTC from IEEE Xplore. Restrictions apply.

we expected to measure similar blood flow values. The presence of calcification increases the vessel wall and the amount of static scatters on the aneurysm sac, resulting in an increased value of K [5], [6].

As a result, accurate K thresholding is necessary to display meaningful real time blood flow information to the surgeon. Fig. 2 shows LSCI blood flow maps before and after clip placement using a narrow and a large K thresholding range. The horizontal lines in Fig. 2(d) represents two K thresholding ranges used to display the LSCI blood flow maps. The narrow K range [0.05, 0.15] (blue dotted lines) is not inclusive of the preclipping value in ROI 1 (K=0.213). Conversely, the large K range [0.05, 0.30] (red dotted lines) is inclusive of K=0.213. The LSCI images pre- and postclipping with a narrow K range are presented in Fig. 2(b) & (c) while the large K range is presented in Fig. 2(e) & (f). As can be observed, only the LSCI blood flow images with the large K range revealed the change in blood flow occurring in the aneurysm sac following clip placement as shown in Fig. 2(e) & (f).

The K thresholding range setting selection is an important factor when displaying real time LSCI blood flow maps. Inadequate K thresholding (Fig. 2(b) & (c)) failed to highlight the change in flow in the clipped calcified aneurysm and did not offer accurate surgical guidance to the surgeon. Before selecting the thresholding settings, it is crucial to gain a comprehensive understanding of the K values across all ROIs prior to the anticipated flow change.

B. *LSCI during Carotid Endarterectomy Surgery*

LSCI was used to assess blood flow during a carotid endarterectomy procedure before excision of the plaque. Our results suggest that our intraoperative LSCI setup and exposure time (T=1.1ms) did not enable blood flow measurements in the exposed carotid artery as presented in Fig. 3. We believe that the thickness of the artery and the presence of atherosclerotic plaques exceeded the penetration depth of LSCI preventing accurate sampling of dynamic scatterers inside the carotid. However, LSCI offered real-time and continuous visualization of the blood flow in the superficial vaso vasorum (e.g.: the sub-millimeter vessels feeding the carotid). In comparison, indocyanine green angiography, the gold standard fluorescence imaging modality used to assess blood flow intraoperatively, was also unable to capture blood flow information in the artery as it failed to detect fluorescence signal from the blood flow in the carotid artery (Fig. 3(c)).

This observation underscores the limitations of LSCI in assessing blood flow within thick arteries, providing valuable preliminary insights into the utility and potential clinical applications of LSCI in the field of vascular surgery. We believe this is the first reported observation where LSCI was used to visualize blood flow in a large extracranial artery.

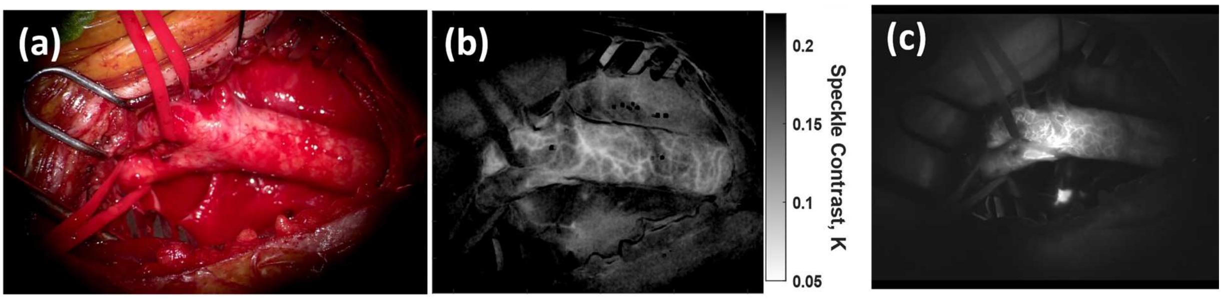

Fig. 3: Blood flow visualization during carotid endarterectomy procedure. (a) White light image of the surgical field of view. (b) Corresponding laser speckle contrast imaging (LSCI). (c) Indocyanine green angiography (ICGA) image captured with IR 800® (Carl Zeiss Meditec, Oberkochen, AG). The ICGA image was taken seconds after (b).

IV. Conclusion

In conclusion, LSCI holds promise as a non-invasive optical technique for intraoperative blood flow assessment in neurosurgery. However, limitations include the influence of static scattering on speckle contrast values and the limited penetration depth of LSCI. Our clinical observations demonstrate the need for precise thresholding of speckle contrast values to ensure accurate blood flow visualization, particularly in the presence of calcified vessel walls. Additionally, LSCI may face challenges in assessing blood flow within thick arteries. These findings contribute to our understanding of the potential applications and limitations of LSCI in guiding complex surgical interventions.

Acknowledgment

Research reported in this publication was supported by the National Institute of Health [NS108484] and Carl Zeiss Meditec AG, Oberkochen. The authors would like to thank the Inselspital, University Hospital, Bern neurosurgeons including Prof. Raabe, Dr. Goldberg and Dr. Bervini as well as the hospital staff for their support and collaborative efforts throughout the clinical trial.

References

[1] D. A. Boas and A. K. Dunn, “Laser speckle contrast imaging in biomedical optics,” J Biomed Opt, vol. 15, no. 1, p. 011109, 2010.

[2] W. Heeman, W. Steenbergen, G. M. van Dam, and E. C. Boerma, “Clinical applications of laser speckle contrast imaging: a review,” J Biomed Opt, vol. 24, no. 08, Aug. 2019.

[3] N. Hecht, J. Woitzik, S. König, P. Horn, and P. Vajkoczy, “Laser speckle imaging allows real-time intraoperative blood flow assessment during neurosurgical procedures,” Journal of Cerebral Blood Flow and Metabolism, vol. 33, no. 7, pp. 1000–1007, Jul. 2013.

[4] D. R. Miller, R. Ashour, C. T. Sullender, and A. K. Dunn, “Continuous blood flow visualization with laser speckle contrast imaging during neurovascular surgery,” Neurophotonics, vol. 9, no. 02, pp. 1-12, Mar. 2022.

[5] A. B. Parthasarathy, S. M. S. Kazmi, and A. K. Dunn, “Quantitative imaging of ischemic stroke through thinned skull in mice with Multi Exposure Speckle Imaging,” Biomed Opt Express, vol. 1, no. 1, pp. 246–259, Aug. 2010.

[6] P. G. Vaz, A. Humeau-Heurtier, E. Figueiras, C. Correia, and J. Cardoso, “Effect of static scatterers in laser speckle contrast imaging: an experimental study on correlation and contrast,” Phys Med Biol, vol. 63, no. 1, p. 015024, Dec. 2017.

[7] K. Khaksari and S. J. Kirkpatrick, “Combined effects of scattering and absorption on laser speckle contrast imaging,” J Biomed Opt, vol. 21, no. 7, p. 076002, Jul. 2016.

Authorized licensed use limited to: University of Oklahoma Libraries. Downloaded on December 17,2025 at 21:45:13 UTC from IEEE Xplore. Restrictions apply.

[8] M. A. Davis, S. M. S. Kazmi, and A. K. Dunn, “Imaging depth and multiple scattering in laser speckle contrast imaging,” J Biomed Opt, vol. 19, no. 8, p. 086001, Aug. 2014.

[9] C. Ayata, A. K. Dunn, Y. Gursoy-Özdemir, Z. Huang, D. A. Boas, and M. A. Moskowitz, “Laser Speckle Flowmetry for the Study of Cerebrovascular Physiology in Normal and Ischemic Mouse Cortex,” Journal of Cerebral Blood Flow & Metabolism, vol. 24, no. 7, pp. 744–755, Jul. 2004.

[10] Laser Institute of America, “American National Standard for safe use of lasers,” 2007.

Authorized licensed use limited to: University of Oklahoma Libraries. Downloaded on December 17,2025 at 21:45:13 UTC from IEEE Xplore. Restrictions apply.