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CASE REPORT

Cortical perfusion measurements with laser speckle contrast imaging during adenosine induced cardiac arrest for aneurysm clipping: a case report

Alexis Dimanche[1] · David Bervini[2] · David R. Miller[3] · Andreas Schär[4] · Johannes Goldberg[2] · Andreas Raabe[2] · Andrew K. Dunn[1]

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Abstract

Adenosine induced cardiac arrest (AiCA) is one of the methods used to facilitate microsurgical aneurysm clipping by providing more visibility and less pressure in the aneurysmal sac and neighboring vessels. We report the use of laser speckle contrast imaging (LSCI) during AiCA to monitor the changes in pulsation and perfusion on the cortical surface during adenosine induced cardiac arrest for aneurysm clipping surgery. Application of this technology for perfusion monitoring may improve workflow and surgical guidance and provide valuable feedback continuously throughout the procedure. ClinicalTrials.gov identifier: NCT0502840.

Keywords Adenosine induced cardiac arrest (AiCA) · Laser speckle contrast imaging (LSCI) · Perfusion monitoring · Aneurysm clipping · Intraoperative blood flow visualization · Cerebral blood flow

Introduction

During microsurgical aneurysm clipping, blood flow causes intra-aneurysmal tension which can increase the risk of aneurysm rupture and complicate the clip placement. To reduce the aneurysmal pressure and risk of rupture, three techniques are routinely used intraoperatively to assist the surgeon in safely placing the clip. These include proximal temporary arterial clipping [2], rapid ventricular pacing [4] and adenosine induced cardiac arrest (AiCA)[5, 6]. During AiCA, a controlled, transient period of cardiac hypotension is induced to the patient. Indeed, adenosine is a short-acting drug with negative effect on sinoatrial and atrioventricular nodes. The sudden reduction in cardiac output diminishes the aneurysmal wall-tension, which facilitates successful clip placement and, thus, reduces the risk of aneurysm rupture.

Previously, laser speckle contrast imaging (LSCI) was employed to investigate changes in cerebral blood flow (CBF) in rat models during cardiac arrest [3], but the dynamics of transient CBF reduction during AiCA have not been visualized in human brain. LSCI is a technique for label-free, full-field, continuous and real-time blood flow monitoring during neurosurgery [1]. In recent years, various feasibility studies have characterized the ability of LSCI to offer real-time and continuous blood flow information intraoperatively during neurosurgery [7–10]. However, the use of LSCI to detect variations in cardiac cycles and monitor associated cortical perfusion changes has not yet been thoroughly studied. We present a case where LSCI was used to continuously measure the CBF changes on the cortex during AiCA. The hardware required for LSCI was attached onto the surgical microscope (Pentero® 900, Carl Zeiss Meditec AG) which allowed continuous visualizations of blood flow during critical moments of the procedure.

Alexis Dimanche and David Bervini contributed equally.

✉ Andrew K. Dunn
adunn@utexas.edu

1 Department of Biomedical Engineering, The University of Texas at Austin, Austin, TX, USA

2 Department of Neurosurgery, Inselspital, Bern University Hospital, University of Bern, Bern, Switzerland

3 Dynamic Light Inc, Austin, TX, USA

4 Department Anaesthesiology & Pain Therapy, Inselspital, Bern University Hospital, University of Bern, Bern, Switzerland

Case report

Patient history

The 51-year-old female patient presented in our outpatient clinics because of migraine. Head MR-Angiography incidentally revealed an intradural internal carotid artery aneurysm on the right hand-side. A diagnostic digital subtraction angiography confirmed a 4-mm aneurysm at the departure of the anterior choroidal artery (AChoA). Microsurgical clipping surgery was offered to the patient.

LSCI data acquisition and image processing

LSCI is based on the analysis of laser speckle patterns which arise when coherent light is backscattered by a medium such as tissue [1]. The LSCI hardware was mounted onto the surgical microscope and integrated into the surgical workflow (Fig. 1). To illuminate the brain and record speckle patterns, a laser diode ($\lambda = 785$ nm) was mounted onto the surgical microscope. The backscattered light was collected via an external camera (1280 × 1024) attached to the surgical microscope side-port. Raw speckle images were captured at a rate of 60 frames per second, utilizing a 1.1-ms exposure time. These images underwent processing to create speckle contrast images with an averaging of four frames, enabling the calculation of the speckle correlation time—an indicator reflecting both blood flow and tissue motion [9]. Speckle contrast blood flow maps were displayed to the surgeon on the operating room screens in real time throughout the surgery. To better visualize the changes in CBF relative to a baseline value, the inverse correlation time was normalized by the first 5 s of the time course data and to the mean value of a static region in the surgical field of view (gauze region).

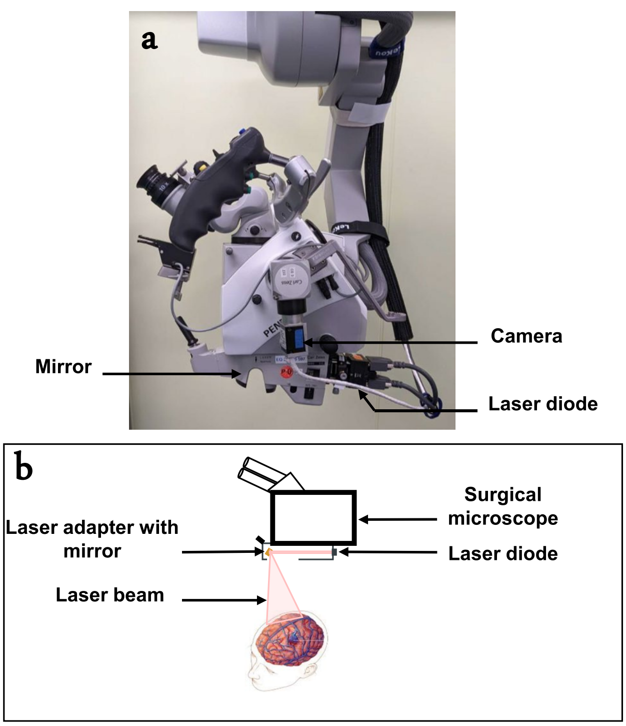

Fig. 1 Laser speckle contrast imaging (LSCI) hardware integration into the surgical microscope. **A**. Photograph of the Pentero® 900 (Carl Zeiss Meditec AG) equipped with the LSCI hardware. **B**. Diagram illustrating the surgical microscope with emphasis on the illumination pathway

Surgical procedure

A standard right pterional craniotomy was performed. A right skull-base and proximal splitting of the Sylvian fissure approach was performed to access and clip the aneurysm. The procedure presented two main challenges. The first concern pertained to the proximity of the aneurysm to the posterior communicating and AChoA arteries which were situated close to, and partially hidden by the aneurysm. Secondly, the AChoA aneurysm looked fragile and dysplastic. The increased pressure and blood volume through the aneurysm, the narrow surgical corridor and the need for manipulation to visualize the surrounding vascular anatomy presented a high chance of aneurysm rupture at the time of clipping. Since the operating surgeons maintained proximal control (internal carotid artery) in case of aneurysm rupture, no external cardiac rapid pacing was planned but instead surgeons relied on AiCA. The AChoA aneurysm was clipped with two clips (Peter Lazic GmbH, Germany) using a stacked technique. AiCA was performed at the time of the second clip placement. We chose adenosine over temporary proximal clipping after evaluating local vascular anatomy and consulting with the anesthesiology team to ensure the safety of AiCA.

To safely overcome these challenges and facilitate the placement of the second clip on the aneurysm, 18 mg of adenosine was administered by rapid intravenous bolus injection and flushed with 20 mL of saline to induce AiCA to the patient. The patient underwent asystole which resulted in a short period of systemic hypotension facilitating the clip placement. Continuous recording of CBF with LSCI during adenosine administration showed the expected decrease in cerebral perfusion experienced by the patient. The timed side-by-side montage in Video 1 compares the surgical microscope video feed to the LSCI measurements during clipping and displays the ~ 5 s of controlled hypotension experienced by the patient starting at $t = 14$ s in the video.

The CBF on the exposed cortical surface (160 × 110 pixel yellow box ROI) (Fig. 2a) was continuously measured prior (Fig. 2b), during (Fig. 2c) and after the cardiac arrest. Figure 3 shows the relative cerebral blood flow changed

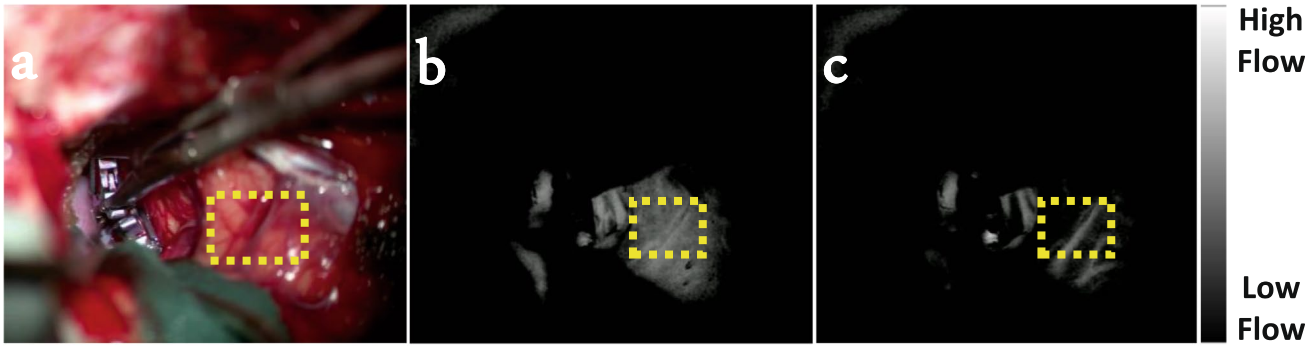

Fig. 2 Laser speckle contrast imaging (LSCI) images of the exposed cortical surface in proximity to the anterior choroidal artery (AChoA) aneurysm. **A**. Surgical microscope image depicting the yellow rectangular region of interest (ROI) on the cortex located in proximity of the aneurysm where the cortical perfusion is visible. **B**. LSCI image illustrating the high perfusion on the cortex following systole (yellow box) **C**. Low perfusion during asystole induced by adenosine induced cardiac arrest (AiCA). Low speckle contrast values depicted in white represent "High Flow," whereas high speckle contrast values depicted in black represent "Low Flow"

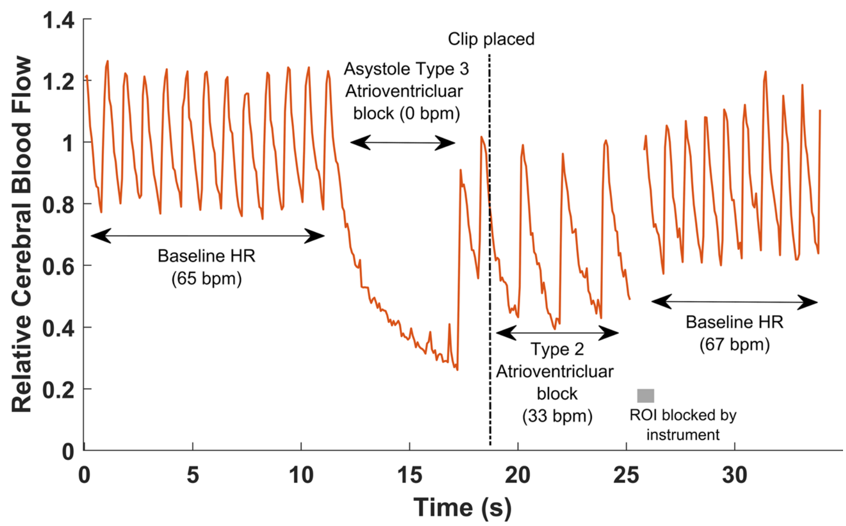

Fig. 3 Cerebral blood flow changes due to adenosine induced cardiac arrest measured with laser speckle contrast imaging (LSCI). The data is from a 160 × 110 pixel region of interest chosen on the cortex of the brain next to the aneurysm. HR heart rate, bpm beats per minute, AV atrioventricular

averaged over the entire cortical region enclosed in the ROI during AiCA. Baseline flow measurements were captured during the 5 s leading to the adenosine injection occurring at approximately 11 s and used to normalize the data time course.

This illustrative case demonstrates the high sensitivity of LSCI to visualize the changes in blood flow during normal cardiac output and during arrest. Our analysis involved computing the average period between peaks resulting from the overall changes in perfusion during the cardiac cycle, as illustrated in Fig. 3. The computed baseline heart rates agreed with electrocardiogram data from the patient. Notably, the ~ 6-s period of asystole (type 3 atrioventricular block), which commenced after 11 s, is clearly captured in Fig. 3 by the sudden drop in CBF to ~ 24% of baseline levels, as well as the absence of cortical pulsations. Following adenosine decay, there was a sudden increase in CBF, and the heart entered type 2 atrioventricular block for ~ 7 s, displaying only half of the ventricular frequency (~ 33 bpm). The decrease in flow and pressure within the aneurysmal sack facilitated safe clip placement, thus reducing the likelihood of aneurysm rupture. Subsequently, the heart recovered to its baseline ventricular frequency of ~ 67 bpm, which illustrated full atrioventricular coupling. Our findings highlight the ability of LSCI to measure expected perfusion changes continuously and non-invasively.

Discussion

Neurosurgery, in particular neurovascular surgery, relies on a robust understanding of the CBF to avoid ischemic events such as stroke. The gold standard intraoperative blood flow visualization modalities such as fluorescence angiography require a contrast agent and, hence, cannot be used continuously throughout the surgery. As a result, these technologies are not able to guide the surgeon throughout the procedure by providing real-time and continuous vessel flow and perfusion measurements.

LSCI can monitor blood flow during neurosurgery. However, few reports have demonstrated visualization of perfusion changes intraoperatively during critical moments of the operation with LSCI. This study highlights the promising clinical use of LSCI to monitor real-time changes in perfusion. Expected changes in cortical perfusion and pulsation following AiCA were accurately recorded and visualized. LSCI measured a minimal flow of ~ 24% of the baseline value which could be explained by the presence of a vessel which remained partially perfused in the ROI. It is unclear whether the relative CBF is expected to reach 0 during AiCA. Therefore, LSCI can be useful in alerting the surgeon to ischemic events. Moreover, the sensitivity of LSCI to the pulsation of the brain resulting from the cardiac cycle informs about the current heart frequency and potential problems in the cardiac cycle.

For the first time, neurosurgeons were able to visualize real-time changes in cortical perfusion induced by AiCA intraoperatively. The changes in pulsatile motion following the modified cardiac cycles induced by adenosine were accurately captured and measured with LSCI. Hence, the case illustrates the potential of LSCI at detecting and alerting the surgeon of ischemic events and sudden changes in perfusion or brain pulsation. Prinz et al. [10] demonstrated FLOW 800's capacity to depict cortical hemodynamic changes post-bypass surgery. Additionally, their study underscored the practical limitations of this modality, which introduced significant variability in perfusion measurements and underscored the higher sensitivity of LSCI in detecting microcirculation changes.

This observation suggests that LSCI can be a viable tool to monitor overall or local brain perfusion and detect hypoperfused regions. This can help the surgeon make better real-time decisions and reduce risks of morbidity associated with ischemia. There were no clinical repercussions noted due to the visualization of LSCI intraoperatively. Further studies are necessary to explore the potential surgical impact of the technology.

Conclusion

This case illustrates the ability of LSCI to measure, visualize and display ischemic areas or changes in pulsation to the surgeon resulting from AiCA. The technique does not use any contrast agent. Hence, LSCI offers a tool to neurosurgeons to enable visualization of CBF changes in real time which can be used continuously throughout the procedure.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1007/s00701-024-05925-2.

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Author contribution **AD**: conceptualization; data curation; formal analysis; investigation; visualization; validation; writing—original draft; software. **DB**: conceptualization; formal analysis; investigation; visualization; validation; writing—original draft. **DM**: data curation; investigation; funding acquisition; project administration; software; writing—review and editing. **AS:** conceptualization; formal analysis; writing—review and editing. **JG**: funding acquisition; project administration; writing—review and editing. **AR**: funding acquisition; project administration; writing—review and editing; supervision. **AD**: visualization; funding acquisition; project administration; software; writing—review and editing; supervision.

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Data availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Code availability The MATLAB code used in this study to post process the data is available upon request to the corresponding author.

Declarations

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the Inselspital, Bern University Hospital and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the local ethics committee in Bern, Switzerland (Project-ID: 2021-D0043).

Consent to participate Informed consent was obtained from all individual participants included in the study prior to the surgery. This study was conducted in accordance with the principles set forth in the Inselspital, University of Bern Research Ethics Committee guidelines.

Consent for publication The subject gave written consent to publish videos, images or clinical images that could reveal their identity.

Conflict of interest Carl Zeiss Meditech AG sponsored the clinical study where the observation was recorded. D. R. M. and A. K. D. disclose a financial interest in Dynamic Light, Inc., in the form of holding stock, serving on the board of directors, and consulting. The terms of this arrangement have been reviewed and approved by the University of Texas at Austin in accordance with its policy on objectivity in research. No other authors disclose a conflict of interest.

References

1. Boas DA, Dunn AK (2010) Laser speckle contrast imaging in biomedical optics. J Biomed Opt 15:011109
2. Charbel FT, Ausman JI, Diaz FG, Malik GM, Dujovny M, Sanders J (1991) Temporary clipping in aneurysm surgery: technique and results. Surg Neurol 36:83–90
3. Crouzet C, Wilson RH, Bazrafkan A, Farahabadi MH, Lee D, Alcocer J, Tromberg BJ, Choi B, Akbari Y (2016) Cerebral blood flow is decoupled from blood pressure and linked to EEG bursting after resuscitation from cardiac arrest. Biomed Opt Express 7:4660–4673

4. Grabert J, Huber-Petersen S, Lampmann T, Eichhorn L, Vatter H, Coburn M, Velten M, Güresir E (2021) Rapid ventricular pacing as a safe procedure for clipping of complex ruptured and unruptured intracranial aneurysms. J Clin Med 10:5406
5. Groff MW, Adams DC, Kahn RA, Kumbar UM, Yang B-Y, Bederson JB (1999) Adenosine-induced transient asystole for management of a basilar artery aneurysm. J Neurosurg 91:687–690
6. Guinn NR, McDonagh DL, Borel CO, Wright DR, Zomorodi AR, Powers CJ, Warner DS, Lam AM, Britz GW (2011) Adenosine-induced transient asystole for intracranial aneurysm surgery. J Neurosurg Anesthesiol 23:35–40
7. Hecht N, Woitzik J, Dreier JP, Vajkoczy P (2009) Intraoperative monitoring of cerebral blood flow by laser speckle contrast analysis. Neurosurg Focus 27:E11
8. Hecht N, Woitzik J, König S, Horn P, Vajkoczy P (2013) Laser speckle imaging allows real-time intraoperative blood flow assessment during neurosurgical procedures. J Cereb Blood Flow Metab 33:1000–1007
9. Miller DR, Ashour R, Sullender CT, Dunn AK (2022) Continuous blood flow visualization with laser speckle contrast imaging during neurovascular surgery. Neurophotonics 9:021908
10. Prinz V, Hecht N, Kato N, Vajkoczy P (2014) FLOW 800 allows visualization of hemodynamic changes after extracranial-to-intracranial bypass surgery but not assessment of quantitative perfusion or flow. Operative Neurosurgery 10:231–239

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