Case series

Preliminary experience with diffuse correlation spectroscopy in acute ischemic stroke neurointerventional procedures

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ABSTRACT

Background Diffuse correlation spectroscopy (DCS) is a non-invasive optical technique that enables continuous blood flow measurements in various organs, including the brain. DCS quantitatively measures blood flow from temporal fluctuations in the intensity of diffusely reflected light caused by the dynamic scattering of light from moving red blood cells within the tissue.

Methods We performed bilateral cerebral blood flow (CBF) measurements using a custom DCS device in patients undergoing neuroendovascular interventions for acute ischemic stroke. Experimental, clinical, and imaging data were collected in a prospective manner.

Results The device was successfully applied in nine subjects. There were no safety concerns or interference with the standard angiography suite or intensive care unit workflow. Six cases were selected for final analysis and interpretation. DCS measurements with photon count rates greater than 30 KHz had sufficient signal-to-noise to resolve blood flow pulsatility. We found an association between angiographic changes in cerebral reperfusion (partial or complete reperfusion established in stroke thrombectomy cases; temporary flow arrest during carotid artery stenting) and those observed intraprocedurally with CBF measurements via DCS. Limitations of the current technology included sensitivity to the interrogated tissue volume under the probe and the effect of local changes in tissue optical properties on the accuracy of CBF estimates.

Conclusion Our initial experience with DCS in neurointerventional procedures showed the feasibility of this non-invasive approach in providing continuous measurement of regional CBF brain tissue properties.

INTRODUCTION

Healthy human brain function critically depends on preserved regulation of cerebral perfusion. The ability to detect and monitor cerebral perfusion has allowed us to diagnose and guide our management in conditions such as acute ischemic stroke (AIS), chronic carotid artery occlusions, and intracranial stenosis.[1 2] Yet, shortcomings of current diagnostic technologies, such as lack of widespread availability, contraindications from the use of contrast agents or radiation, qualitative rather than quantitative measurements, and cost often restrict wider use of these diagnostics in clinical settings. This is especially relevant in highly time-demanding emergent scenarios where neurointerventionalists, stroke and critical care physicians, and neurosurgeons increasingly practice.[2]

Diffuse correlation spectroscopy (DCS) falls within a broader class of optical techniques that use diffusion of light to measure tissue properties, including of the brain tissue.[3] The most common of these are cerebral oximeters based on near-infrared spectroscopy (NIRS).[4 5] NIRS devices measure the relative absorption of light by different wavelengths to estimate concentrations of oxygenated hemoglobin, deoxygenated hemoglobin and hence tissue oxygen saturation, or blood volume changes. Such measurements are far less accurate in injured tissue.

DCS quantitatively measures blood flow from temporal fluctuations in the intensity of diffusely reflected light caused by the dynamic scattering of light from moving red blood cells within the tissue. DCS has previously been used to directly measure cerebral blood flow (CBF) in brain-injured adults in various clinical settings such as carotid endarterectomy, cardiac bypass surgery, traumatic brain injury, and anoxic brain injury.[6–9]

Despite the number of attractive features of DCS, including its versatility, non-invasive nature, and the ability to provide continuous quantitative measurements of CBF, the utility and application of this imaging modality in acute clinical settings, such as during stroke thrombectomy or other emergent neurointerventional procedures, is quite limited and mainly exists in the form of case reports.[10] Here, we present our initial experience using DCS in conjunction with acute neuroendovascular interventions for AIS and discuss a potential rational for utilization and clinical relevance of DCS-generated data.

METHODS

Participants

Our Institutional Review Board approved the study protocol. Once consent for participation was obtained from the patient or legal authorized representative, the device was applied, and experimental, clinical, and imaging data were collected prospectively. Adult patients presenting to the emergency department diagnosed with AIS were screened for study participation. Pregnant women

and vulnerable populations were excluded from participation in the study.

DCS device

CBF optical measurements were performed using a custom-built DCS instrument (online supplemental figure 1).[11] Commercial DCS instruments to measure CBF are not widely available, therefore we used a custom/laboratory-built device. The device itself does not require extensive calibrations, because the measurements of blood flow are based on normalized intensity autocorrelation functions. Briefly, the DCS instrument features a long coherence length (>5 m) wavelength stabilized turn-key laser (iBeam Smart, Toptica Photonics, 785 nm, 120 mW optical power) to illuminate the tissue via a multimode fiber optic cable (200 micrometer diameter, NA=0.5). Light reflected from the tissue (2.5 cm away on the tissue surface) is collected by two collocated single-mode fibers (5 micrometer diameter) and is directed to a single-photon counting avalanche photo diode module (SPCM-4AQC, Excelitas, Canada). We recorded the light detected by single-photon counting detectors using a data acquisition device (cDAQ9174, with NI9401 digital input/output module, National Instruments, Austin, TX, USA) and converted it to intensity autocorrelation functions using a custom software correlator based on methods described elsewhere.[11] DCS autocorrelation functions were recorded at a data rate of 20 Hz.

The proximal end of the source and detector fibers connected to the DCS device were embedded in bio-safe silicon rubber to create fiber optic probes as described previously.[12] Light from the laser was split using a 50:50 fiber coupled splitter and directed to two fiber optic probes which were applied to the *temporal* and *frontal regions* matching the standard locations for transtemporal (middle cerebral artery (MCA) territory) and transorbital (anterior cerebral artery territory) acoustic windows for the insonation of cerebral arteries used for transcranial Doppler measurements. At each location, DCS measurements were performed with two detector channels. The probes were secured to the patient's head using medical grade tape (3M) at the desired measurement sites. The average illumination power at the tissue surface was measured to be 25 mW, which is less than the recommended American National Standard for Safe Use of Lasers (ANSI) limits (ANSI Z136.1 Safe Use of Lasers) for light-skin interaction. The device application was not allowed to interfere with or delay standard care given the acute nature of cases included in our series.

CBF measurements and analysis

DCS intensity autocorrelation functions measured from both detectors were averaged to increase signal-to-noise ratio. Intensity autocorrelation functions were then fit to the homogeneous semi-infinite geometry solution to the correlation diffusion equation to estimate an index of blood flow in diffusion units (cm^2/sec).[13] Here, we assumed that the tissue absorption coefficient was $\mu_a = 0.1\ cm^{-1}$ and reduced scattering coefficient was $\mu_s' = 10\ cm^{-1}$.

Clinical and imaging data

Baseline and follow-up demographics, imaging and clinical data, and stroke severity on admission and during hospitalization were recorded prospectively per study protocol. Angiographic assessments of thrombectomy procedures were performed using the modified Thrombolysis in Cerebral Infarction (mTICI) grading scale.[14] The degree of carotid stenosis was measured according to the North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria.[15]

RESULTS

Nine patients were selected for this study, and the device was successfully applied in all nine subjects from January 1, 2023 to February 28, 2023. Average age was 69 years and six subjects (67%) were female. There were no safety concerns or interference with the standard angiography suite workflow. In three cases, subsequent DCS data processing revealed that contact probe recordings were compromised due to lead malfunction, making these data non-diagnostic (online supplemental table 1). Six cases were selected for final analysis and interpretation.

The clinical, diagnostic, and procedural summary of these six individual case presentations and the corresponding DCS findings are summarized in table 1. Depending on the case type, either continuous recordings (10–15 min in length) or intermittent recordings (60–120 s in length) were obtained from bilateral temporal and/or frontal regions. DCS measurements were generally not temporally averaged if the recorded signal had sufficient signal-to-noise ratio. Per previous work,[11] DCS measurements with photon count rates greater than 30 KHz had sufficient signal-to-noise to resolve blood flow pulsatility. Data not fitting this criterion were temporally averaged before blood flow estimation.

We observed an association between abnormal radiographic findings and real-time CBF measurements intraproceduraly, which included changes in DCS measurements in response to reperfusion: temporary flow arrest during carotid artery stenting in case 1, abnormal angiographic findings with corresponding symptoms in cases 2 and 4, and successful reperfusion following thrombectomy passes in stroke thrombectomy in case 6. Cases 3 and 5 revealed no radiographic pathology suggesting acute large vessel occlusion (LVO). Four individual case examples of different clinical scenarios with corresponding DCS findings follow.

Case 1 – carotid artery stenting

A patient in their 60s presented to the emergency department with left eye amaurosis fugax. The National Institutes of Health Stroke Scale (NIHSS) was 0 on admission, CT angiography (CTA) demonstrated approximately more than 90% left internal carotid artery (ICA) stenosis, and MRI showed no acute ischemia. Carotid artery stenting was planned with a combination of a distal filter and balloon guide catheter to minimize the risk of embolic complications and was performed on day 3 of admission. Continuous DCS recording of bilateral temporal regions was performed (figure 1A) with balloon guide catheter inflation before crossing the lesion with a filter, and a rapid ~80% drop in ipsilateral CBF was noted. Once the stenting procedure was completed, and the guide catheter balloon was deflated, near immediate normalization of CBF was observed (figure 1A and B). The contralateral CBF recording remained unchanged during the intervention. The procedure was performed under conscious sedation. The patient was examined at the end of the intervention and was neurologically intact.

Case 2 – intracranial stenosis

A patient in their 20s presented with transient right hemispheric symptoms (left hemibody weakness) which completely resolved in the emergency department with NIHSS 0. CT perfusion (CTP) imaging showed increased Tmax>4 s in the right hemisphere, whereas automated perfusion analysis with RAPID

Table 1 Clinical, imaging, and procedural description of individual cases.

Case/category	Presentation	Type of anesthesia, procedure, outcome	DCS findings
Patient 1 CAS	(figure 1) Age 60s. Left eye amaurosis, left ICA 90% stenosis, NIHSS 0	CS. CAS using a balloon guide catheter for flow arrest	Transient ipsilateral drop in CBF during balloon inflation. Unaffected CBF recording contralaterally throughout the case
Patient 2 AIS	(figure 2) Age 60s. NIHSS 7 with right hemispheric symptoms, resolved completely. CTP "nearly" symmetric	CS. DSA on day 3 showed flow-limiting right ICA intracranial stenosis. A new right hemispheric stroke occurred the following week	Asymmetry in temporal CBF, right higher than left
Patient 3 AIS	(figure 3) Age 80s. NIHSS 17 with left hemispheric syndrome. CTP symmetric and no LVO on CTA	GA. Taken for DSA and possible thrombectomy. No LVO on DSA. No intervention	Symmetric temporal recording
Patient 4 AIS	Age 70s. "Wake up" stroke with minimal symptoms (fluctuating NIHSS 0–1.) CTA with left M1 occlusion, possibly chronic. CBV and CBF symmetric on CTP; MTT and TTP prolonged on left side	No DSA, no intervention. Tiny embolic left occipital stroke on MRI	Asymmetric temporal and frontal recordings
Patient 5 CAS	Age 60s. Asymptomatic chronic severe left ICA stenosis (likely underlying dissection)	CS. Several attempts to cross the lesion with a guidewire were unsuccessful, CAS aborted	Continuous DCS recording throughout the case, symmetrical fluctuations between the two sides
Patient 6 AIS	(figure 4). Age 40s. NIHSS 14, right hemispheric syndrome, right M1 occlusion on CTA	CS. Thrombectomy with two passes: (TICI 2b after first pass, TICI 2c after second pass)	Continuous DCS recording; increased CBF on right side correlated with angiographic reperfusion

AIS, acute ischemic stroke; CAS, carotid artery stenting; CBF, cerebral blood flow; CBV, cerebral blood volume; CS, conscious sedation; CTA, computed tomography angiography; CTP, computed tomography perfusion; DCS, diffuse correlation spectroscopy; DSA, digital subtraction angiography; GA, general anesthesia; ICA, internal carotid artery; LVO, large vessel occlusion; M1, middle cerebral artery M1 segment; MRI, magnetic resonance imaging; MTT, mean transit time; NIHSS, National Institutes of Health Stroke Scale; TICI, Thrombolysis in Cerebral Infarction; TTP, time to peak.

(iSchemaView, Inc.) software was "symmetric" (figure 2A). Non-invasive angiography questioned high-grade intracranial ICA stenosis. Digital subtraction angiography (DSA) was performed on day 3, which showed near-occlusion of the right ICA intracranially (figure 2B). A brief DCS recording in the angiosuite showed consistent flow with some asymmetry between the two hemispheres (figure 2C). The patient was discharged on "best medical management" per the current guidelines. The patient presented to the emergency department the following week with recurrent, persistent, mild, right hemibody weakness. Repeat imaging showed acute infarct in the right hemisphere (figure 2D), and DSA showed complete right ICA occlusion intracranially (not shown in the figure).

Case 3 – acute stroke thrombectomy aborted

A patient in their 80s was admitted with a suspected AIS, left hemispheric syndrome, NIHSS 17. CTP showed no perfusion deficit (figure 3A) and CTA head showed no LVO (figure 3B). Due to the high degree of clinical suspicion for LVO stroke and poor visualization of the extracranial vessels on CTA, the patient was taken emergently to the angiosuite where DSA (figure 3C) showed no visible occlusion extra- or intra-cranially, thus no thrombectomy was performed. DCS was recorded in the angiosuite and showed no asymmetry between the two hemispheres (figure 3D).

Case 4 – acute stroke thrombectomy

A patient in their 40s presented with left hemiparesis and neglect, NIHSS 14. Non-invasive imaging showed right MCA M1 occlusion. The patient was taken for emergent thrombectomy under general anesthesia. DCS leads were briefly applied bilaterally to the anterior temporal regions (figure 4A) on the patient's arrival to the angiosuite. Continuous DCS recordings were obtained throughout the thrombectomy procedure once guide catheter access was established and M1 occlusion was confirmed (figure 4B). With two passes, TICI 2b and 3C was achieved, respectively (figure 4C). The patient made a remarkable clinical recovery; repeat imaging the following day showed a minimal final stroke burden on MRI (figure 4D).

DISCUSSION

Our study showed the feasibility of measuring regional CBF with DCS technology in the acute phase of AIS in the angiography suite. Importantly, there were no safety concerns or disruption of routine workflow which attest that this new technology can be successfully applied to this population of patients. As seen in figure 4, the profile of the device is small, and therefore does not interfere with angiographic assessment of cerebral vasculature. Experience with DCS technology for cerebrovascular technologies remains limited. Sathialingam *et al* applied DCS in an intensive care unit to patients with non-traumatic subarachnoid hemorrhage to quantify CBF changes in response to intrathecal nicardipine administration.[16] The authors noted a heterogeneous response across subjects and an association with development of delayed cerebral ischemia. In another study, Kaya *et al* tested changes in CBF in patients undergoing carotid endarterectomy.[6] They showed that intraprocedural transient clamping of carotid arteries results in ipsilateral decrease in blood flow measured via continuous DCS, similar to the findings of transient CBF changes observed in our patients undergoing CAS.

To our knowledge, only two cases of DCS recordings in patients undergoing endovascular thrombectomy (EVT) were reported in the peer-reviewed literature.[10] The first case was an intracranial ICA occlusion treated with EVT, and the second case was a cervical occlusion treated with emergent stenting. The study concluded that DCS demonstrated a recanalization-induced increase in ipsilateral CBF with minimal change in extracerebral blood flow. Based on the data gathered from our

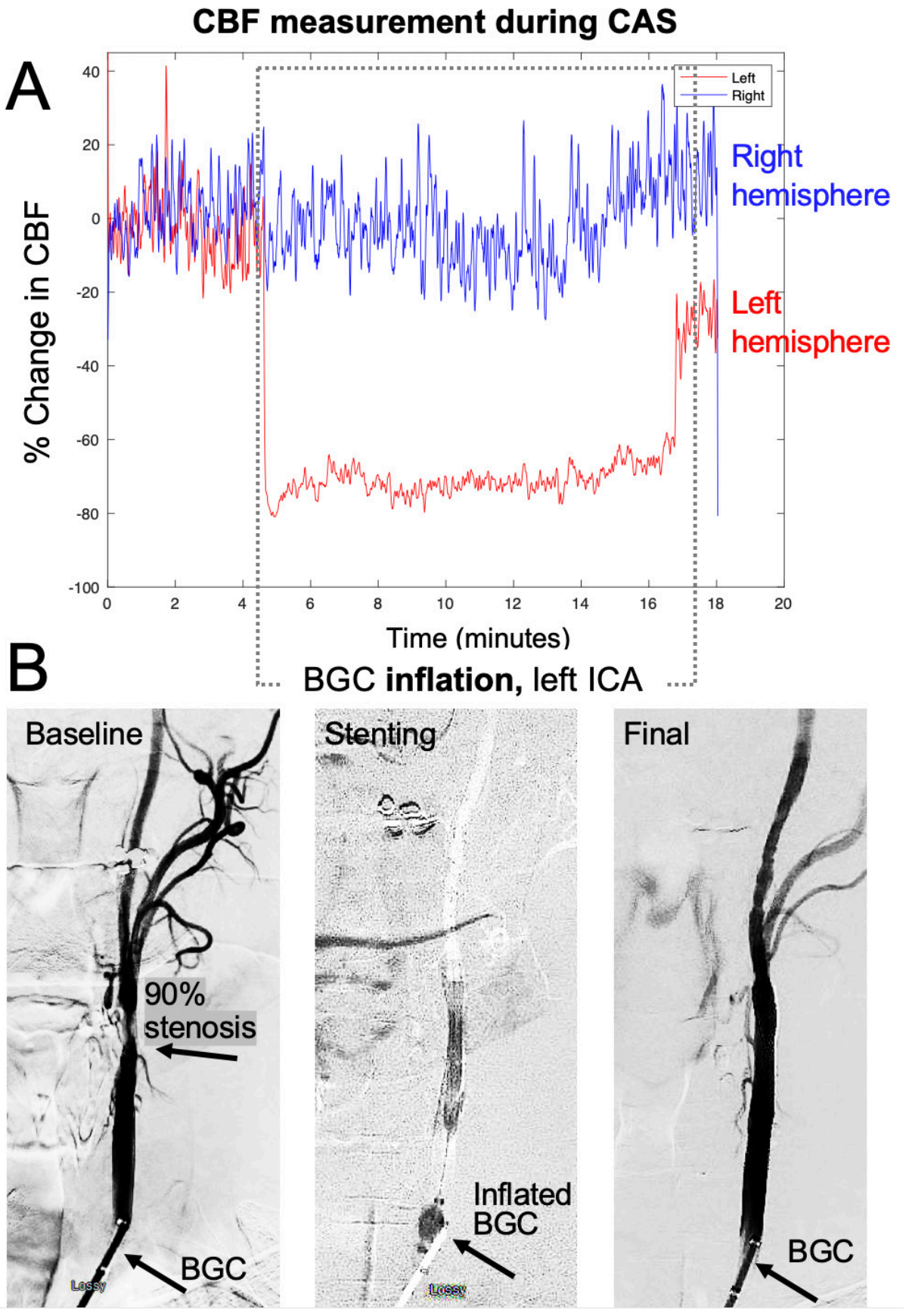

Figure 1 Left carotid artery stenting (CAS) with a balloon guide catheter (BGC). (A) Continuous bilateral temporal diffuse correlation spectroscopy recordings during the procedure where a BGC was used to induce transient flow arrest. A reversible drop of cerebral blood flow (CBF) on the side of the occlusion (red). The control contralateral side (blue) remained unaffected. (B) Baseline angiography with 90% internal carotid artery (ICA) origin stenosis, stenting, and final post-stenting digital subtraction angiography images are shown.

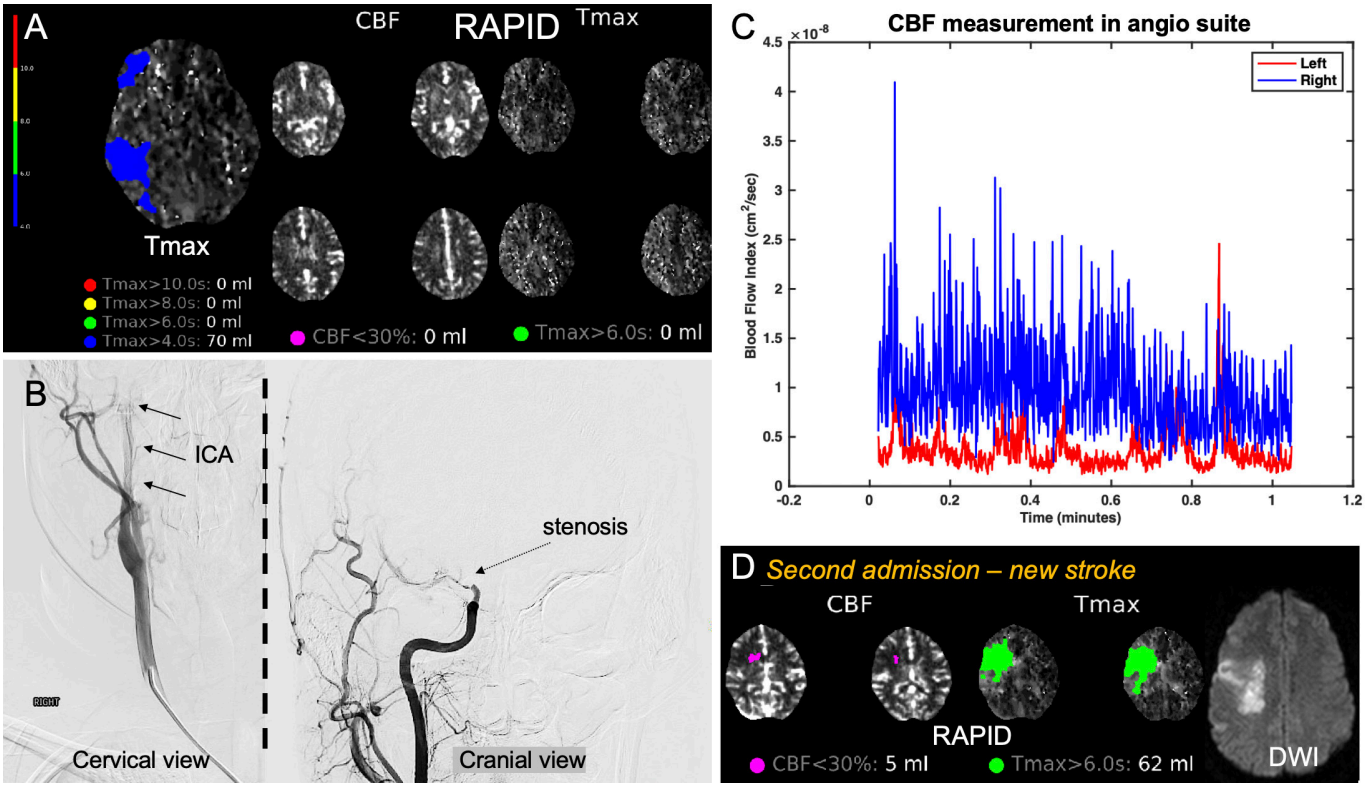

Figure 2 Flow-limiting right internal carotid artery (ICA) intracranial stenosis. (A) CT perfusion (CTP) with elevated Tmax>4 s in the watershed territory, right hemisphere. Automated perfusion analysis with rapid software (iSchemaView, Inc.) showed symmetric cerebral blood flow (CBF) <30% and Tmax>6.0 s calculations between the two hemispheres. (B) Digital subtraction angiography, cervical and intracranial views, showed delayed filling of the right ICA (arrows) and middle cerebral artery from flow-limiting focal supraclinoid stenosis (dashed arrow). (C) CBF asymmetry is recorded on diffuse correlation spectroscopy. (D) A week later, the patient developed a new stroke within the right hemisphere, seen on CTP rapid images and MRI diffusion-weighted imaging (DWI) sequence. Repeat angiography demonstrated complete occlusion of the right ICA intracranially (not shown).

six-patient series, we believe that compensatory augmented blood flow via the external carotid artery (ECA) may occur in the context of intracranial LVO (such as due to ICA or proximal M1 blockage). This could potentially impact DCS measurements depending on the depth of the area being recorded. The phenomenon of increased pulsation of the ECA branches in a setting of ICA occlusion was described by Miller Fisher in 1970.[17] Imaging findings on the role of ECA flow in a setting of ICA occlusion are currently controversial, possibly due to major heterogeneity of the presentations, types of occlusion, and diagnostic modalities used to study this phenomenon.[18]

We note a few limitations of our study. First, as described earlier, DCS blood flow measurements are sensitive to the interrogated tissue volume under the probe (usually a depth of 1–2 cm below the surface). However, the depth sensitivity of the measurements is not uniform. We have previously shown that flow changes in the superficial tissue layers (in this case, the scalp) may confound the sensitivity of the measurements to CBF changes.[12] Typically, this is more significant for measurements of small acute changes in blood flow, such as in functional activation, rather than large changes, such as in reperfusion. Similar to the approach by Forti *et al*,[10] we use a 2.5 cm source detector separation to estimate CBF; this ensures that our measurements are sufficiently sensitive to cerebral tissues. Further, our experimental design compares CBF or CBF changes across different hemispheres. This internal control measurement reduces the impact of superficial flow contamination since systemic flow changes would affect both hemispheres equally.

Second, our estimate of blood flow is based on assumed values for tissue absorption and reduced scattering coefficients. Local changes in tissue optical properties may affect the accuracy of CBF estimates. Ideally, these properties are measured in situ for each patient. Prior research has shown that large inaccurate assumptions for scattering coefficients impact DCS-CBF estimates.[19] However, this effect was drastically reduced for small errors in assumptions of tissue scattering, which is clinically more probable. Moreover, an intrinsic control measurement (from contralesional hemisphere) improves our confidence in our interpretation of the results. Future implementations of more robust DCS instruments, such as our recently developed pathlength-resolved DCS device, could alleviate these limitations.[20]

Research on the utility and value of DCS in a critical care setting (traumatic brain injury, vasospasm, and AIS) is currently in its infancy. This is in at least in part due to the fact that until recently, very few laboratories could achieve a reliable non-invasive recording of CBF. Furthermore, limited commercial availability of DCS makes it challenging for a broad clinical audience to adopt and validate this technology. The most innovative aspect of this emerging technology is our ability to continuously assess cerebral perfusion and cerebral tissue health, in real time. We do acknowledge that the clinical value of DCS in the angiosuite could be limited. Instead, DCS might find its best use in a pre-hospital setting (such as detection of LVO), intraoperatively (as a neuromonitoring tool), or in the neurointensive care unit. However, for early experience and device optimization, we chose the angiosuite environment.

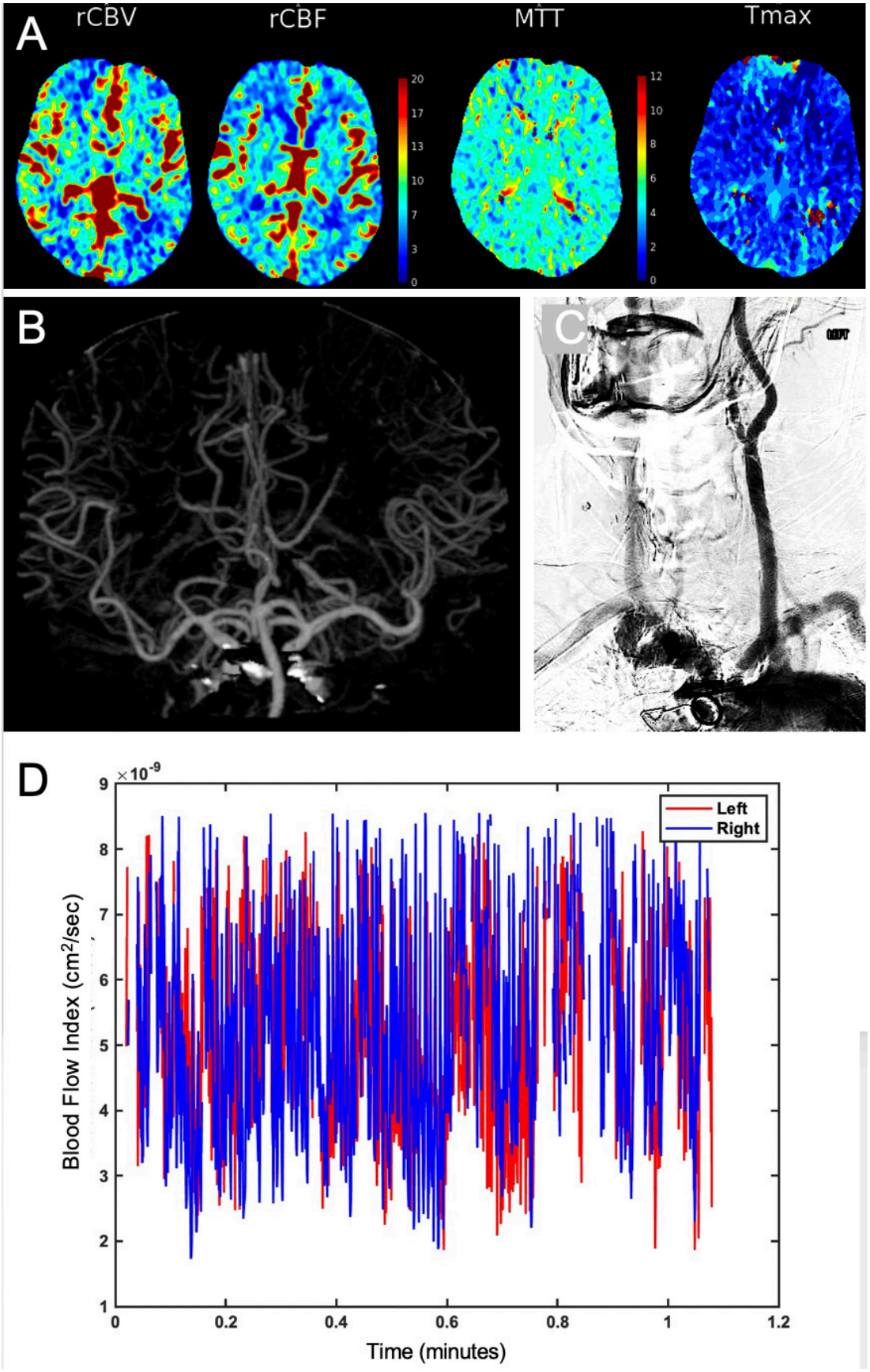

Figure 3 Acute ischemic stroke, aborted thrombectomy. (A) CT perfusion maps with no asymmetry between the two hemispheres. (B) Three-dimensional CT angiography reconstruction showing patent intracranial vessels. (C) Digital subtraction angiography, aortic arch run, showing patent extracranial vessels. (D) Symmetric blood flow indexes between the two hemispheres. MTT, mean transit time; rCBF, relative cerebral blood flow ; rCBV, relative cerebral blood volume.

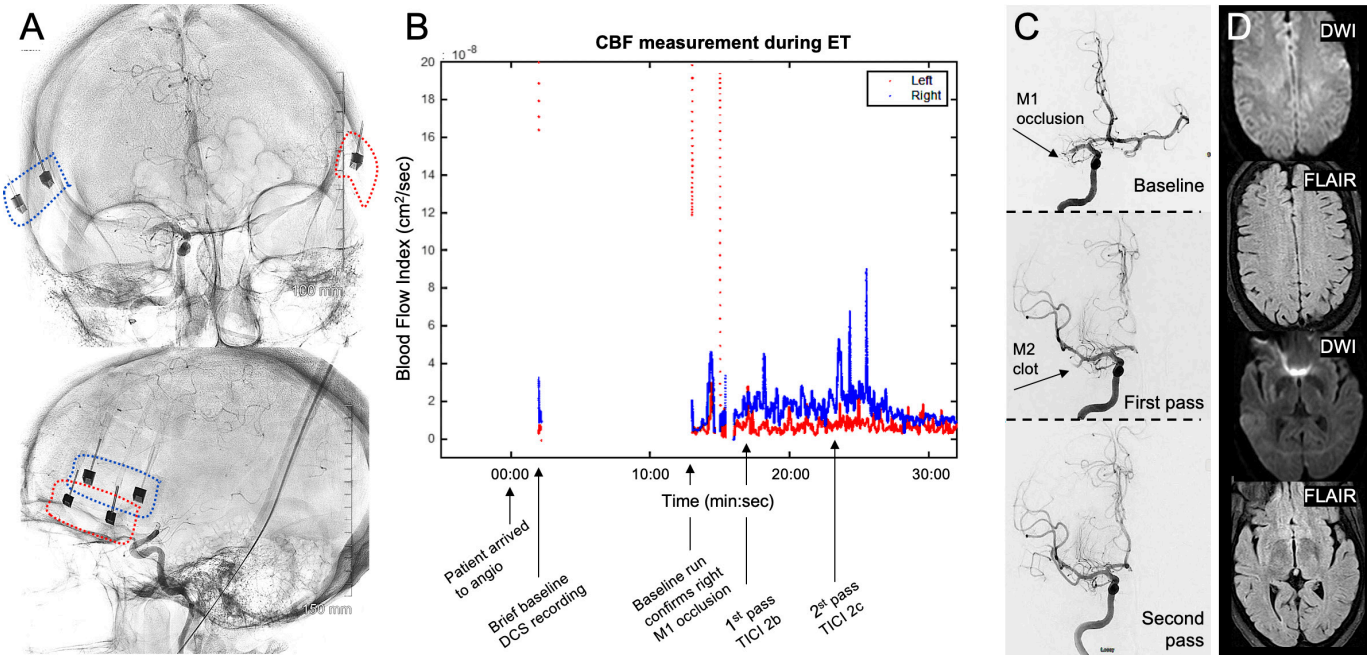

Figure 4 Right middle cerebral artery (MCA) M1 thrombectomy. (A) Angiography, unsubtracted coronal and lateral views, right M1 occlusion. Position of the right (blue) and left (red) diffuse correlation spectroscopy (DCS) probes at the anterior temporal regions is shown. (B) Cerebral blood flow (CBF) recorded with DCS, starting from the patient's arrival to the angiosuite, and continuing throughout the entire endovascular thrombectomy (ET) procedure. Note the instant increase in CBF on the side of the M1 occlusion once Thrombolysis in Cerebral Infarction (TICI) 2b reperfusion is achieved after the first pass TICI 2b. (C) Digital subtraction angiography of the right M1 occlusion at baseline, after the first pass, and after the second pass. (D) MRI was performed the following day showing minimal residual stroke on the diffusion-weighted imaging (DWI) and fluid-attenuated inversion recovery (FLAIR) sequences.

CONCLUSIONS

Our initial experience with DCS in neurointerventional procedures showed the feasibility of this non-invasive approach in providing continuous measurement of regional CBF brain tissue properties. Potential clinical applications of this novel approach include real-time physiological monitoring of cerebrovascular function, paving the way for personalized treatments, precision medicine, and improved patient outcomes.

In the future, implementations of more robust DCS instruments, such as our recently developed pathlength-resolved DCS device, could alleviate the limitations of the current DCS technology discovered during this study.

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Contributors MM, WSB, ABP: study concept and design. WRG, MM, IP, ST, KV: data collection. ABP: statistical analysis. MM, ABP: wrote the draft manuscript. All authors: edited the manuscript and approved the final version.

Competing interests MM: grant: NIH; consultant: Cerenovus, Medtronic; stock options: Bendit Technologies, Borvo Medical, BrainQ, Endostream, Serenity Medical, Synchron, Sim&Cure, QAS.AI, Quantanosis.AI; Assistant Editor for JNIS. WSB: grant: Athersys, BMS, Florida High Tech Corridor, NIH, Reneuron, VuEssence; consultant: Genentech, VuEssence; stock options: VuEssence; other: PRIME Education. ABP: grant: NIH; stock options: SPKL LLC.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and the IRB of the University of South Florida (STUDY000320) approved the study. Participants gave informed consent to participate in the study before taking part.

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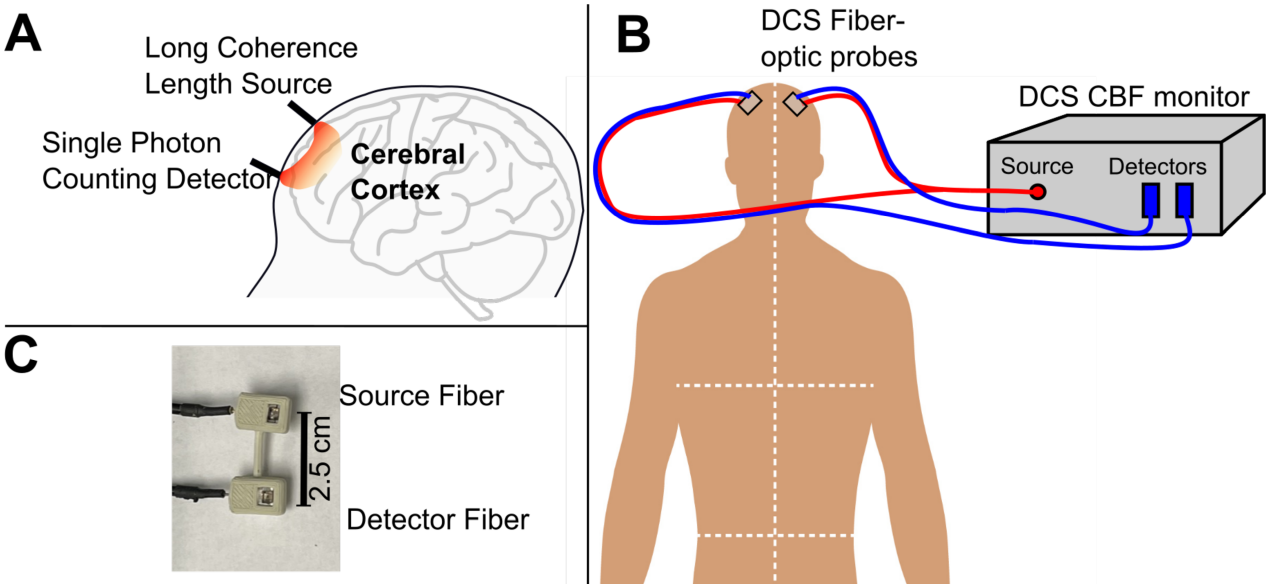
REFERENCES

1 Hochberg AR, Young GS. Cerebral perfusion imaging. *Semin Neurol* 2012;32:454–65.
2 Wintermark M, Sesay M, Barbier E, *et al*. Comparative overview of brain perfusion imaging techniques. *Stroke* 2005;36:e83–99.
3 Durduran T, Yodh AG. Diffuse correlation spectroscopy for non-invasive, micro-vascular cerebral blood flow measurement. *Neuroimage* 2014;85 Pt 1:51–63.
4 McCormick PW, Stewart M, Goetting MG, *et al*. Noninvasive cerebral optical spectroscopy for monitoring cerebral oxygen delivery and hemodynamics. *Crit Care Med* 1991;19:89–97.
5 Gopinath SP, Robertson CS, Contant CF, *et al*. Early detection of delayed traumatic intracranial hematomas using near-infrared spectroscopy. *J Neurosurg* 1995;83:438–44.
6 Kaya K, Zavriyev AI, Orihuela-Espina F, *et al*. Intraoperative cerebral hemodynamic monitoring during carotid endarterectomy via diffuse correlation spectroscopy and near-infrared spectroscopy. *Brain Sci* 2022;12:1025.
7 Zavriyev AI, Kaya K, Farzam P, *et al*. The role of diffuse correlation spectroscopy and frequency-domain near-infrared spectroscopy in monitoring cerebral hemodynamics during hypothermic circulatory arrests. *JTCVS Tech* 2021;7:161–77.
8 Busch DR, Balu R, Baker WB, *et al*. Detection of brain hypoxia based on noninvasive optical monitoring of cerebral blood flow with diffuse correlation spectroscopy. *Neurocrit Care* 2019;30:72–80.
9 Kim MN, Durduran T, Frangos S, *et al*. Noninvasive measurement of cerebral blood flow and blood oxygenation using near-infrared and diffuse correlation spectroscopies in critically brain-injured adults. *Neurocrit Care* 2010;12:173–80.
10 Forti RM, Favilla CG, Cochran JM, *et al*. Transcranial optical monitoring of cerebral hemodynamics in acute stroke patients during mechanical thrombectomy. *J Stroke Cerebrovasc Dis* 2019;28:1483–94.
11 Wang D, Parthasarathy AB, Baker WB, *et al*. Fast blood flow monitoring in deep tissues with real-time software correlators. *Biomed Opt Express* 2016;7:776–97.

12 Baker WB, Parthasarathy AB, Ko TS, *et al*. Pressure modulation algorithm to separate cerebral hemodynamic signals from extracerebral artifacts. *Neurophotonics* 2015;2:035004.
13 Boas DA, Meglinsky IV, Zemany L, *et al*. 1997 Spatially varying dynamical properties of turbid media probed with diffusing temporal light correlation. *J Opt Soc Am*
14 Zaidat OO, Yoo AJ, Khatri P, *et al*. Recommendations on angiographic revascularization grading standards for acute ischemic stroke. *Stroke* 2013;44:2650–63.
15 Barnett HJM, Taylor DW, Haynes RB, *et al*. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. *N Engl J Med* 1991;325:445–53.
16 Sathialingam E, Cowdrick KR, Liew AY, *et al*. Microvascular cerebral blood flow response to intrathecal nicardipine is associated with delayed cerebral ischemia. *Front Neurol* 2023;14.
17 Fisher CM. Facial pulses in internal carotid artery occlusion. *Neurology* 1970;20:476–8.
18 van Everdingen KJ, Klijn CJM, Kappelle LJ, *et al*. MRA flow quantification in patients with a symptomatic internal carotid artery occlusion. *Stroke* 1997;28:1595–600.
19 Irwin D, Dong L, Shang Y, *et al*. Influences of tissue absorption and scattering on diffuse correlation spectroscopy blood flow measurements. *Biomed Opt Express* 2011;2:1969–85.
20 Safi AM, Moka S, Harrah M, *et al*. Quantitative measurement of static and dynamic tissue optical properties with continuous wave pathlength resolved diffuse correlation spectroscopy. Optics and the Brain; Washington, DC. Washington, DC: OSA Technical Digest (Optica Publishing Group), 2021

Supplemental Data

Preliminary experience with diffuse correlation spectroscopy in acute ischemic stroke neurointerventional procedures



Supplemental Figure 1. **Cerebral blood flow measurements with Diffuse Correlation Spectroscopy.**
(A) Schematic of conventional DCS measurement highlighting sensitivity to Cerebral cortex.
(B) Schematic of measurement with two representative optical probes placed over the frontal cortex. Red lines indicate source fibers, blue lines indicate detector fibers.
(C) Representative image of fiber optic probe with source and detector fibers separated by 2.5 cm. Optical fibers were coupled to a 3mm prism for efficient probe-tissue light coupling.

Supplemental Table 1. **Description of 3 cases excluded from Diffuse Correlation Spectroscopy data analysis.**

Case	Presentation	Reason for exclusion
Subject 1.	Age 80s. Acute stroke with left M1 occlusion.	Faulty lead, DCS data non-diagnostic
Subject 2.	Age 90s. Acute stroke with right M1 occlusion.	Faulty lead, DCS data non-diagnostic
Subject 3.	Age 90s. Acute stroke with left M1 occlusion, recanalization after intravenous tPA.	Faulty lead, DCS data non-diagnostic

Abbreviations: DCS, diffuse correlation spectroscopy; M1, middle cerebral artery M1 segment; tPA, tissue plasminogen activator.