Novel Intraoperative Cerebral Blood Flow Monitoring by Laser-Doppler Scanner

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Abstract

Laser-Doppler (LD) flowmetry was used to measure tissue perfusion non-invasively and continuously during neurosurgical operations using an LD scanner. Scanning was usually completed in 20 seconds. Measurements were processed in software to provide a color-coded image of the tissue perfusion. Moreover, the measurement data, expressed in LD-units, could be used for statistical data analysis. No physical contact was necessary between the scanning device and the exposed brain tissue. The imager provided two-dimensional microvascular flow maps non-invasively and quantitatively during brain operations, and could show the CO₂ reactivity in the vessels. LD scanning flowmetry is a promising intraoperative monitoring method for cerebral blood flow changes.

Key words: cerebral blood flow, laser-Doppler flowmetry, scanning technique, intraoperative monitor

Introduction

Laser-Doppler (LD) flowmetry is a relatively new technique first used for the measurement of skin microcirculation in 1975. The technique has now gained acceptance as an effective method for the measurement of blood perfusion in various clinical and research areas, in the neurosurgical field as well as in wound healing, dermatology, diabetology, and vascular biology. LD flowmetry is easy to use, and allows the measurement of blood perfusion continuously, non-invasively, and in real time.¹

The conventional, single-point method of LD flowmetry is still widely used. The recently developed experimental method of LD scanning allows non-contact measurement of perfusion over a larger area of the brain surface. LD scanning can compensate for the weaknesses of conventional single-spot LD flowmetry in the rat brain, as scanning provides superior spatial resolution local cerebral blood flow ( rCBF ) to regional cerebral blood flow ( rCBF ) and can provide an absolute rCBF value in various circumstances. Other advantages include the easy detection of low-flow areas and a better comparison of data from individual experiments. Furthermore, cortical CBF mapping provides information about the ICBF in individual locations.

Clinical trials of the LD scanner have been in progress in various fields of medicine, for example, dermatology, rheumatology, vascular disorders, and burn assessment. The present study investigated a novel medical instrument that permits non-contact CBF measurement, and can provide an image of blood flow in the capillaries under the human brain surface during neurosurgical operations.

Method

1. Monitoring technique

The LD scanner ( moorLDI™ ) was manufactured by Moor Instruments Limited ( Millwey Axminster, U.K. ). The imager scans a low-power He-Ne laser beam in a raster pattern over the brain tissue surfaces, and detects blood cell movement in the microvasculature as a Doppler shift. The system consists of the He-Ne laser, a scanning head, an optical detector unit, a stand, a computer with system software, and a plotter. The scanner is positioned on the mobile stand so that the low-power laser beam successively scans the brain tissue from just above the operative field. The maximum scanning area is from 10 cm × 10 cm at 20-cm distance to 50 cm × 50 cm at 100-cm distance. The scanning speed is under 5 minutes (depending on the scanning area and number of pixels), typically 20 seconds for a 15 cm
× 15 cm image at 64 × 64 pixel resolution. The time required for complete scanning is proportionate to the total number of measuring sites. Moreover, a choice between high- and low-resolution imaging allows zooming-in on a specific tissue area with a preselected number of measurement sites. When the scanning procedure is completed, an image is automatically generated and image analysis can be performed. The CBF value is expressed in arbitrary units. The blood flux is measured on a scale mapped onto a 16-color scale for display purposes. The measurement data, including the measurement parameters, image, and color-coded image, are saved in the computer memory for further data analysis including statistical estimation.

II. Materials

The intraoperative monitor was used in sequential 10 neurosurgical cases. Among them, the CO₂ reactivity in the human brain was examined using the system during neurosurgical operations in six patients (4 incidental aneurysms, 2 epilepsy surgeries). The study was done under normocapnia (at ca. 40 mmHg) and hypocapnia (at ca. 30 mmHg).

Results

I. Intraoperative LD imaging

Figure 1 shows an intraoperative photograph and a color-coded image after the scanning procedure. The scanner was quick and simple to use, and could measure the blood flux over a large area of the brain without contact with the brain surface and produced high-resolution color scans. The scanner image allowed real-time in vivo observation of the cerebral microcirculation under pathological as well as physiological conditions during the neurosurgical operation. The imaging was available in all 10 cases.

Illustrative case: A 34-year-old woman presented with right mild hemispheric stroke. The diagnosis was moyamoya disease. She underwent superficial temporal artery (STA)-middle cerebral artery (MCA) anastomosis and encephalo-myo-synangiosis. The distal end of the STA was anastomosed to the suprasylvian cortical branch of the MCA with 10-0 monofilament sutures in end-to-side fashion. The intraoperative color-coded image by LD scanner showed good flow after vascular reconstruction and the territory of the additional blood supply from the bypass (Fig. 2). The bypass patency was examined by Doppler sonography. Postoperatively, the patient remained symptom-free with stable neurological deficit. Follow-up angiography revealed good filling of the MCA vessels through the direct and indirect bypass.

II. CO₂ reactivity

The mean arterial blood pressure values at normocapnia (at 39.3 ± 0.9 mmHg) and hypocapnia (at 31.3 ± 1.2 mmHg) were 86.5 ± 6.1 mmHg and 78.5 ± 4.9 mmHg, respectively (the difference was not significant). Calculation of the median rCBF values in each brain demonstrated a significant decline from 97.7 ± 16.1 LD-units to 71.9 ± 16.0 LD-units (p < 0.05, paired t-test).

Discussion

I. LD flowmetry

LD flowmetry is relatively non-invasive and allows rapid and continuous measurement of blood flow. The blood flow is calculated from the Doppler shift of a low-power laser beam reflected off moving red blood cells. The non-invasive nature of LD flowmetry is particularly useful for detecting early signs of vascular dysfunction. Therefore, LD flowmetry is no longer considered a research tool and is now used in clinical investigations. However, LD flowmetry has ill-defined spatial resolution (the spatial resolution is limited to a volume of 1–2 mm³), is of limited utility for the evaluation of absolute CBF, and is highly dependent on the localization of the LD probe and the underlying anatomical substrate.

II. LD scanning technique

LD scanning is among the most investigated techniques in experimental fields. The LD probe is moved to multiple predefined positions in the cranial window using a precision positioning procedure with a computer-controlled motorized micromanipulator to measure the ICBF in many different locations. Information from enough locations can compensate partially for the absence of absolute blood flow measurements. This technique allows a more representative measurement of the blood flow by considering the spatial heterogeneity of the blood flow. It is important to have a good understanding of the physiology of the microcirculation to improve the effectiveness and appropriate interpretation of the output signal.

III. LD scanner

The LD scanner can provide clinical information over a much larger area of the skin microcirculation. We applied this technique to monitoring the human brain intraoperatively. Clinical measurement and research requires a method to quantify rCBF. The measurement data obtained from this methodology can be used for statistical analysis. We could also demonstrate the CO₂ reactivity in the intact brain in the present study. Changes in
cerebrovascular responses after various pathological conditions (for example, head injury, acute stroke, and other disorders) are closely related to the outcome and also the occurrence of symptomatic vasospasm after subarachnoid hemorrhage. Moreover, intraoperative imaging can visualize the perfusion status of the brain in arteriovenous malformations, aneurysms, brain tumors, epilepsy surgery, and so on. The technique can detect cortical activation and ischemic conditions, and can assess the circulation in grafts and transplanted organs, and evaluate the results of vascular reconstruction (as shown in Fig. 2). Intraoperative activation studies using this technique may offer helpful information about the anatomical correlation between lesions to be resected and functional areas. No physical contact involving the risk of infection is necessary between the scanning device and the brain, so that the sterilization problems are eliminated.

A possible disadvantage is the high sensitivity to motion-produced artifacts. However, small movements caused by breathing do not cause additional spectral components affecting the measurement.

In conclusion, the LD perfusion imager is a promising new technique for accurate numerical measurement and pictorial representation of the CBF during neurosurgical operations. The technique can reveal phenomena previously undetected by conventional techniques, and might be helpful to reduce postoperative complications.

References


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Commentary

The authors have described the technique for laser Doppler (LD) scanning as a means of evaluating cerebral blood flow during intracranial surgery. Unlike LD flowmetry, LD scanning provides a non-invasive means of measuring perfusion over a large area of brain. The advantages of this method for monitoring cerebral blood flow include the fact that the technique is non-invasive, rapid, continuous and in real time. The authors have elegantly illustrated the benefits of this modality as a promising new technique for evaluation of cerebral blood flow during neurosurgical operations. This publication should certainly stimulate further evaluation of this promising technology.

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The authors describe a fascinating new variation on laser Doppler CBF techniques, using a laser scanner to give a semi-quantitative measurement of flow in a whole area of exposed cortex. As discussed, this has obvious advantages in avoiding contact with the brain surface, thus reducing the risk of infection or local injury. It also avoids the problem of small localized areas where flow may be different, and thus can, for example, detect small areas of ischemic flow. It does not of course provide continuous measurement or postoperative measurement. This technique is likely to be very useful in assessing changes in local or regional blood flow after surgical revascularization, as in one of their cases, and for measuring vascular reactivity, with possible usefulness in surgery after head injury or subarachnoid hemorrhage, as well as for tumors involving blood vessels. I hope we will see further evaluation of this application of laser Doppler scanning in the future.

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