Clinically Available Optical Topography System

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OVERVIEW: Progress in medical imaging has led to remarkable advances in medical diagnosis technology. Nevertheless, the realization of advanced medical treatment requires functional imaging technology that is more practical. In contrast to morphological imaging, functional imaging captures information about the functioning of living tissues, such as blood circulation and oxygen metabolism, cerebral nervous system function and metabolic changes in various bio-materials. In recent years, progress in MRI (magnetic resonance imaging) technology has made it possible to measure circulatory system and cerebral nervous system functions in the form of images and MRI holds promise for realizing diagnostic functional imaging. MRI systems, however, are large and expensive, and they place many restrictions on the patient, which makes MRI impractical for small children and psychiatric patients in particular. There is thus a need for the development of a diagnostic system that is capable of advanced functional diagnosis, yet is not burdensome to the patient. Hitachi, Ltd. is developing an optical topography system that can make advanced brain function measurements conveniently without severe restrictions on the patient and is making progress in developing technology for the clinical application of that system. This work promises to make possible the advanced diagnosis of cerebral diseases in ordinary hospitals, whereas such diagnosis is currently available only in large medical centers.

INTRODUCTION

IN 1977, focusing on the low invasiveness and convenience of the application of optical analysis to functional diagnosis, the results of experiments on using near-infrared light (700–1,200 nm) to measure changes in cerebral blood flow were published, which had an invigorating effect on research in optical functional imaging[1].

On the other hand, reflection-type oxygen monitoring techniques, which utilize the information carried by reflected light that is scattered within the brain, were developed in the 1980s. Reflection-type oxygen monitoring measures light absorption in the vicinity of the cerebral cortex, which is located about 20 mm from the scalp, and so can be used to monitor cerebral blood flow. In 1993, a technique for measuring the changes in blood flow that accompany brain function by means of reflection-type oxygen monitoring was tried, at which time a signal that was synchronized with the examinee’s brain function was measured simultaneously with the blood flow signal. The feasibility of brain function measurement by means of reflection-type oxygen monitoring was thus demonstrated[2–5].

Hitachi, Ltd., while proceeding with research on optical applications for imaging diagnosis, turned attention in 1995 to the importance of functional imaging and attempted to measure brain function distributions by means of reflection-type oxygen monitoring. The results of mapping experiments in which test subjects performed repeated hand movements alternated with relaxed states while signals were measured at successive positions on the subjects head, confirmed an increase in blood flow near the central fissure that corresponded to the hand motor area. In this way, it was verified that brain function distribution can be measured by multi-point reflection-type oxygen monitoring[6–8].

On the basis of the above results, we proceeded to develop the Optical Topography System, which images changes in cerebral blood flow in the form of a topograph. To accomplish simultaneous multi-point measurement, the measurement technique was combined with a technique for detecting the measurement signal by using multiple frequency modulation of the laser light source and an array of

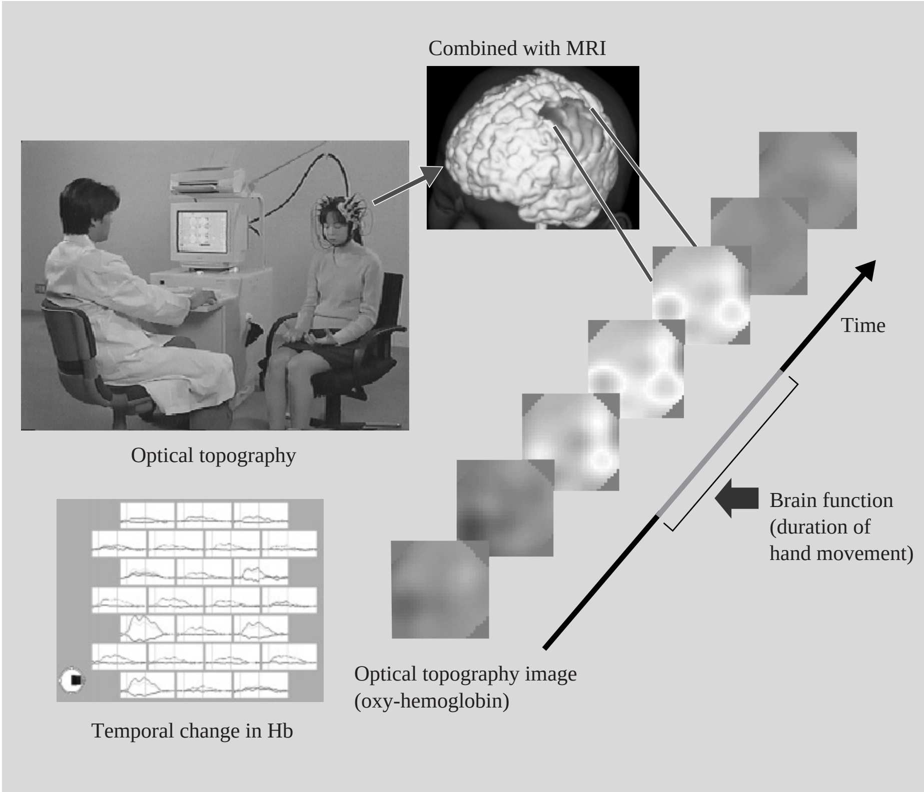


Fig. 1— Brain Function Measurement by Optical Topography.
Optical topography, which can conveniently and non-invasively measure changes in cerebral blood flow in the examinee in the form of an image, makes clinical application of advanced brain function measurements possible.

lock-in amplifiers. Also, using a flexible optical fiber for the probe made it possible to measure brain function at any point on the head.

In 1997, Hitachi Medical Corp. developed the ETG100 Optical Topography System, which has advanced functionality and targets clinical use.

Here, we describe this Optical Topography System, which is applicable to clinical brain function imaging.

OPTICAL TOPOGRAPHY

Measurement Principle

Changes in the amounts of oxy-hemoglobin and deoxy-hemoglobin, the two forms of hemoglobin in the blood, can be measured from two-wavelength absorption data obtained by employing near-infrared light absorption characteristics. The ETG100 Optical Topography System of Hitachi Medical Corp. employs 780-nm and 830-nm laser light sources. If near-infrared light is injected from above the scalp and the output light is measured over a distance of from 2 to 5 cm across the scalp, the measured light passes through the regions inside the skull that are illustrated in Fig. 2, thus making it possible to take measurements of the cerebral cortex. The ETG100 employs an injection and detection distance of 30 mm and experiments have confirmed that brain function can be measured in this way[6].

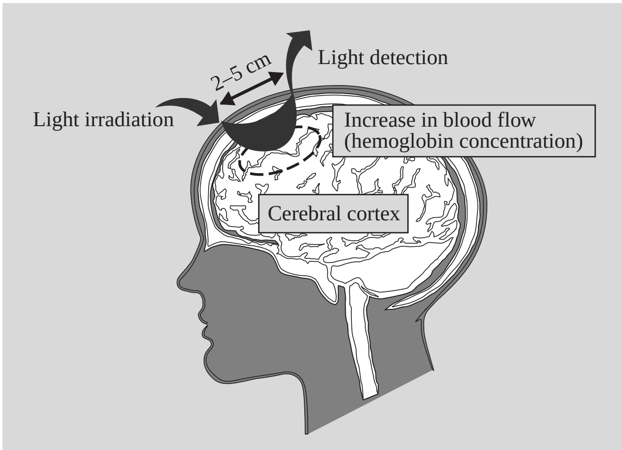


Fig. 2— Mechanism for Cerebral Cortex Measurements by Means of Reflected Light.
Near-infrared light injected from the scalp passes through the cerebral cortex and is detected at the scalp.

In optical topography, brain function distribution can be measured in a non-invasive way by taking measurements at multiple points simultaneously. Many blood vessels are distributed over the cerebral cortex, supplying blood to the cerebral tissues. Thus, if activity is high in a particular area, the blood supply to that area increases and the level of oxy-hemoglobin increases. Furthermore, the consumption of oxygen

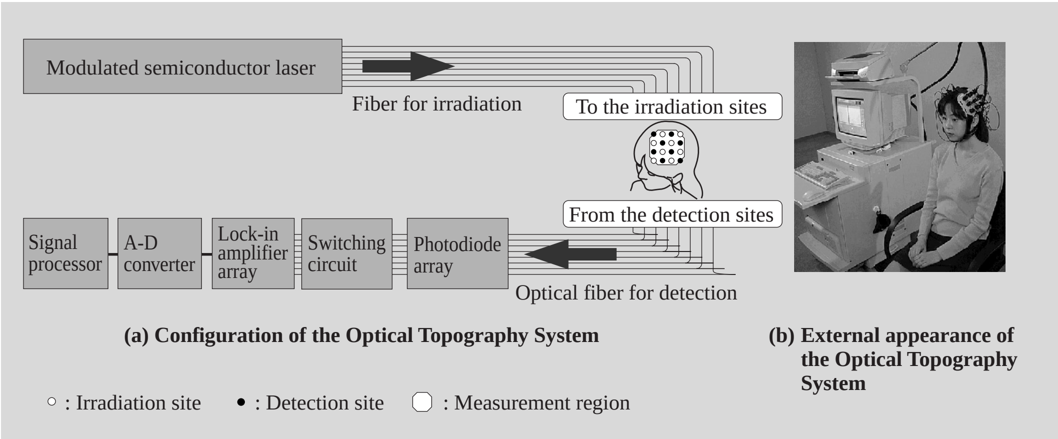


Fig. 3— Configuration and appearance of the Optical Topography System.
The light irradiation and detection are accomplished by means of optical fibers and the signals are processed and displayed.

by cerebral activity produces an increase in deoxy-hemoglobin, so these conditions can be measured as a topographical image.

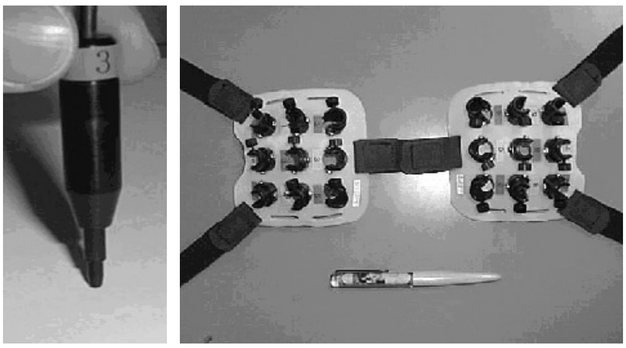
System Configuration

The configuration and external appearance of the ETG100 are shown in Fig. 3.

Laser light, which is modulated at a particular frequency for each wavelength and channel by the light source, is directed at the scalp of the examinee by optical fibers. The probes, which have fine tips to prevent interference from the hair on the scalp, are held firmly against the head. The area is then illuminated and the reflected light is detected (Fig. 4). The detected light is carried by the optical fiber to a highly sensitive photodetector for measurement. The signals from the detectors pass through a switching circuit that is set according to the configuration of the measuring probes and are separated by a lock-in amplifier that is locked to the modulation frequency of the light source. Those signals are measured simultaneously in intervals of at least 0.1 s by 48 individual circuits, analyzed according to wavelength and the regions through which they pass, processed, and the result is displayed in the form of an image that represents changes in hemoglobin amount.

Measurement Probe Configurations

The measurement probe comprises light sources and detectors arranged alternately in a specified lattice configuration. Users install the probes by inserting them into sockets in standard holders according to instructions from the program (Fig. 4). The ETG100 comes with three probe configurations, from which one can be selected according to the type of measurement needed (Fig. 5). Of those configurations, the two-surface 3×3 configuration is used to assess left-right brain dominance in motor, auditory and language brain functions. The 4×4 configuration is used for functional localization measurements, such as measurements of the visual cortex, and for fine measurements of areas on one side of the brain. The 3×5 configuration is long in one direction, and so useful for simultaneous measurements of Broca’s area and Wernicke’s area, which are important in language function research, for example.



(a) (b)

Fig. 4— Probe (a) and Holder (b).
Probes are set in specified positions in the holder and the probe tips are placed in contact with the scalp.

	Mode 1 (3 × 3)	Mode 2 (4 × 4)	Mode 3 (3 × 5)
Areas measured	2	1	1
Number of probes	Light sources: 10 Detectors: 8	Light sources: 8 Detectors: 8	Light sources: 8 Detectors: 7
Probe configuration ● : Light sources ○ : Detectors	● ○ ● ● ○ ● ○ ● ○ ○ ● ○ ● ○ ● ● ○ ●	● ○ ● ○ ○ ● ○ ● ● ○ ● ○ ○ ● ○ ●	● ○ ● ○ ● ○ ● ○ ● ○ ● ○ ● ○ ●

Fig. 5— Measurement Probe Configurations.
The illuminating and detecting probes are arranged in a lattice according to program specifications. The user selects the mode to match the measurement area.

Processing of the Measurement Signal

In the signal processor, changes in the levels of the two types of hemoglobin are calculated from changes in the two-wavelength measurement signal, using absorption spectra. The ETG100 has two measurement sequences. The first is a continuous measurement mode in which change is monitored continuously from the time measurement begins. That mode is used for monitoring seizures of cerebral diseases. The second sequence is the integration mode, in which test periods are alternated with periods of rest for the examinee. The signal that is output during the relaxed state is used as the reference for extracting the test signal, and the results for the repeated test periods are added and averaged. That makes it possible to accurately measure weak responses. An example of the signal for the response to movements of the left hand measured in the right brain hemisphere in the integration mode with a 4 × 4 probe configuration is shown in Fig. 6.

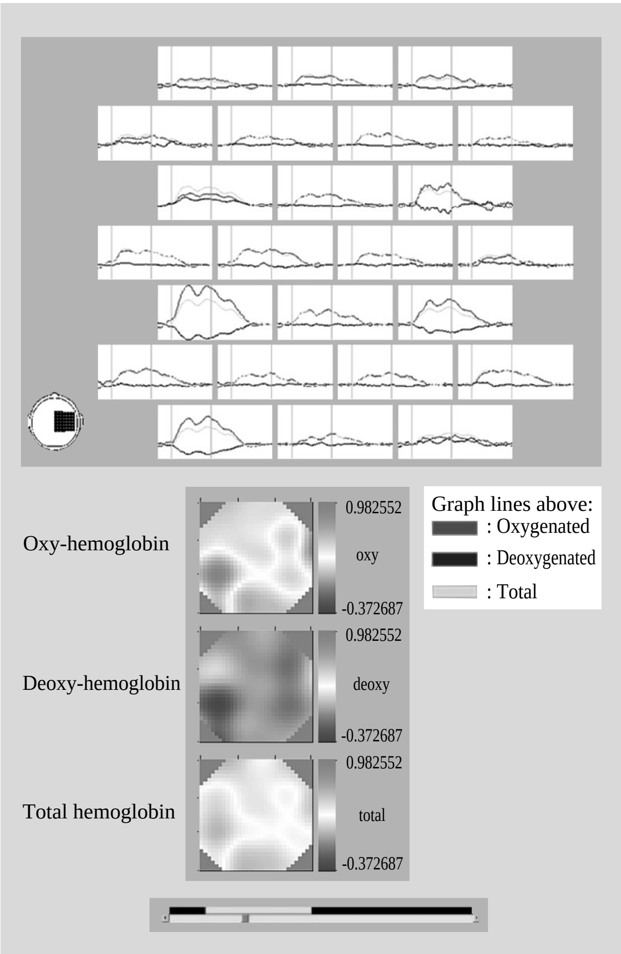


Fig. 6— Optical Topography Image of the Hand Motor Area.
The right hemisphere response to left hand movements is measured with the 4 × 4 mode. An increase in oxy-hemoglobin in the vicinity of the motor area can be seen.

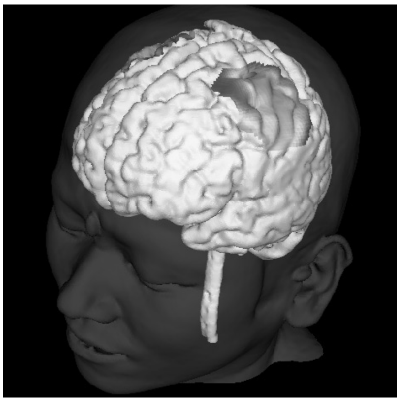


Fig. 7— Optical Topography Results Superimposed on an MRI Image.
The increase in oxy-hemoglobin during hand movements is displayed in combination with an MRI image.

An increase in oxy-hemoglobin due to increased blood flow in the vicinity of the motor area can be seen in Fig. 6. This was measured simultaneously for the left and right brain hemispheres with the 3 × 3 probe configuration. The results of those measurements combined with an MRI image are shown in Fig. 7.

As described above, the Optical Topography System is capable of dynamically measuring changes in hemoglobin level in the cerebral cortex in two dimensions. The features of this system with respect to clinical application include (1) the possibility of long-term measurements and repetitive measurements, (2) the examinee is allowed some degree of movement and application to small children is possible, (3) the equipment is compact and portable, so bed-side examination is possible, and (4) external noise has little effect on the measurements, so a special examination room is not required.

CLINICAL APPLICATION OF THE OPTICAL TOPOGRAPHY SYSTEM

Because it provides convenient brain function measurement, the Optical Topography System can be used for measuring various brain functions, such as motor and sensory functions, visual and auditory functions, and high-order functions related to language and consciousness, and for the measurement of the visual cortex during sleep, visual stimulus and response during anesthesia and changes in cerebral blood flow under trans-cranial magnetic stimulation, etc.

On the basis of these results, we are currently proceeding with application to the diagnosis of brain function impairments, particularly for children and newborns, with the aim of clinical application. We are also trying to diagnose cerebral infarctions and other such blood flow diseases by comparison of responses to stimuli to those of healthy persons. In addition to the use of stimulus-response-type cerebral changes, clinical applications that employ spontaneously occurring fluctuations in blood flow are also possible. The spontaneous fluctuations that can be measured by optical topography include a fluctuation of about 1.0 Hz due to pulsation and respiration at about 0.3 Hz, and a fluctuation of close to 0.1 Hz of unclear origin. The relation of these fluctuations to the optical topography signals and the understanding of the physiological mechanisms behind them are expected to have connections to clinical uses. Furthermore, the pulsed changes that occur during epileptic seizures may be useful in confirming the location of the seizure focus.

CONCLUSIONS

We have described the features of the Optical Topography System as well as its use in brain function measurement techniques and future application in clinical situations.

The Optical Topography System, a system for simple and convenient functional diagnosis that has been newly developed by Hitachi Medical Corp., is expected to find wide use in future diagnosis and treatment and for bed-side measurement. Moreover, it may be possible that the information obtained from the dynamic measurement capability of optical topography will be used in new diagnostic techniques. We will continue with research and technical improvement of this system, with the aim of widespread use of optical topography as a non-invasive functional diagnostic system that can be used for comfortable examination of children and the elderly.

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