Development of Optical Topography System ETG-100

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Summary

We developed Optical Topography®※1 (OT) system ETG-100 to advance the clinical application of noninvasive measuring system for brain function.

Along with proceeding the clinical evaluation of the ETG-100 we developed some techniques which can contribute to improve the performance and functionality of OT. Those include high-resolution optical measuring technique, high performance optical probe and 3-dimentional display system.

Key Words: Optical topography, Noninvasive, Brain Function

1. Introduction

Hitachi Ltd. and Hitachi Medical Corporation have proceeded study of "Optical Topography System" that allows to measure the change of cerebrall blood flow and metabolism to be noninvasively and simply measured and visualized. Further we have developed a new brain function measuring technique using this system to show feasibility of brain function measurement by the optical topography [1)2)]. In addition, we have proceeded a clinical diagnostic system targeting brain function diagnosis based on these techniques, and developed the Optical Topography System ETG-100 especially by improving the measuring probe and interface functionality taking utilization in general hospitals into consideration. This system is under evaluation in various medical institutions, and actually used in more than 20 domestic and overseas institutions and hospitals. Until now, studies on from high level brain function such as development and processing of speech to infant brain function disease, and further a wide range of applications from brain blood flow diagnosis to ischemic brain disease diagnosis have been investigated. These results are expected to help a wide range of clinical applications such as in the psychiatric department, cerebral nerve department, pediatrics and dental departments [3)~11)].

Moreover to improve performance of the optical topography based on these results, we are conducting improvement of various related techniques such as high-precision optical measuring and optical source techniques, data display technique to apply measuring results to diagnosis. This report introduces you to the overall aspects of the Optical Topography System ETG-100 and optical topography related techniques under development, and further the latest clinical results obtained with this system.

2. Optical Topography System ETG-100

General principles and basic composition of the optical topography system have been already reported [1)]; therefore, this paper will present its overview with ETG-100 as an example[12)~15)].

2.1 System composition

Fig. 1 shows the general view of the system and Fig. 2 shows its composition. The optical topography system is composed of the light source unit to generate modulated laser light, optical fiber for irradiation to transmit it to the patient, optical fiber for detection to collect light from the brain surface, measuring circuit to separate and measure detected optical signals, and data conversion, processing and display units.

Laser light modulated by frequencies different in wavelength and position for irradiation is lead through the optical fiber and radiated from the probe contacting the region for study. Light collected at a position 2~3cm apart from the incident point is converted to an electric signal by the optical detector. Signals from the detector are mixed with light from multiple positions for irradiation. Therefore, they are distributed to the lock-in amplifiers tuned to modulation frequencies of measuring light through the switching circuit corresponding to the layout of measuring unit, and signals corresponding to combination of specific optical sources and detectors are extracted. These signals are measured at the same time in a 0.1 seconds interval, and after classified according to each wavelength and measuring region, they are converted to change of hemoglobin quantity and displayed as an image.

2.2 Measuring layout

The probe of optical topography system ETG-100 is composed of 10 elements for light source and 8 elements for detection. With these arranged in a grid on the measuring plane, the probe effectively measures distribution of optical absorption on the cerebrum surface of measuring area. The user can correctly set the probe by following instructions of the program to insert the probe tip into the standard holder for fixing the probe set to the patient head (Fig. 3). In addition, this system is provided with three types of measuring layouts shown in Fig. 4 allowing the user to select any optimum measuring layout according to the position and stretch of measuring object. Among these, the 2-plane type of 3×3 is used for measurement of motor or auditory function that is divided into the left and right of cerebrum, judgment of the superior side of speech function which dominance is at the left or right. Also, the layout of 4×4 is used when any function is localized in an area such as optic area. 3×5 is laterally long and used for simultaneous measurement of both Broca and Wernicke speech area localized at the front and rear of temporal cerebrum.

Fig. 1

General View of Optical Topography System (ETG-100)

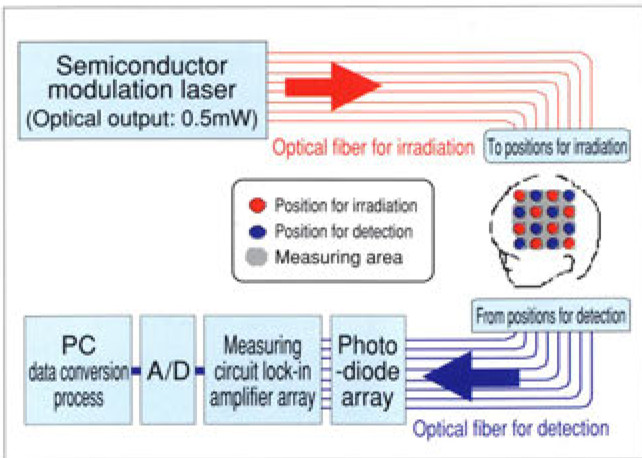


Fig. 2

Composition of Optical Topography System (RTG-100)

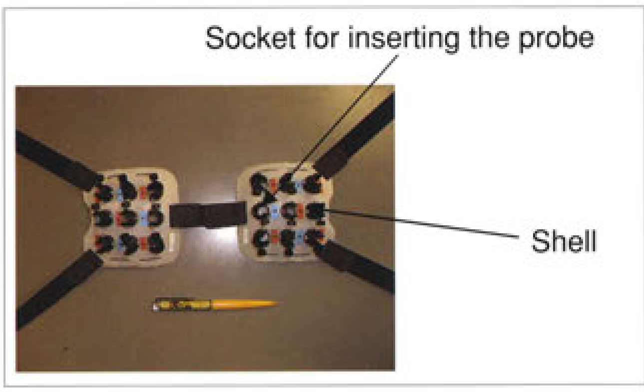


Fig. 3

Probe Holder

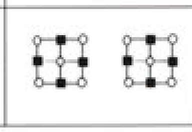
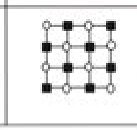
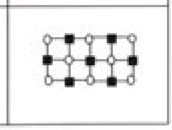
Measurement array	3×3	4×4	3×5
Probe ○ Light source ■ Detection			

Fig. 4

Layout of Measuring Probes

2.3 Measuring signal processing

From change of measuring signals with two wavelengths, change of oxygenation and deoxygenation hemoglobin (Hb) quantity is calculated using optical absorption spectrum of both materials. In addition, this system includes two types of measuring modes.

The first measuring mode continuously monitors change of Hb quantity from starting measurement, and can be utilized to monitor operations and epileptic seizure. Fig. 5 shows an example of Hb signal measurement in epileptic seizure. Measuring results can be displayed by selecting either of the time course graph maps showing three types of Hb temporal change for oxygenation, deoxygenation and total, or three topographic images composed based on the above three graphs. Also, topography image can be displayed in the cine mode. The second measuring mode is the integration method used in fMRI and so on, which repeatedly gives stress and rest in a constant interval to measure reaction from difference between stress and rest. Further repeating this to obtain added mean improves accuracy of measurement. With this, cerebrum activity hard to measure due to small signal change can be correctly measured. Fig. 6 shows an example of signals from motor area by hand motion. Increase of oxygenation Hb is observed in an area near the motor area at the reverse side of hand motion.

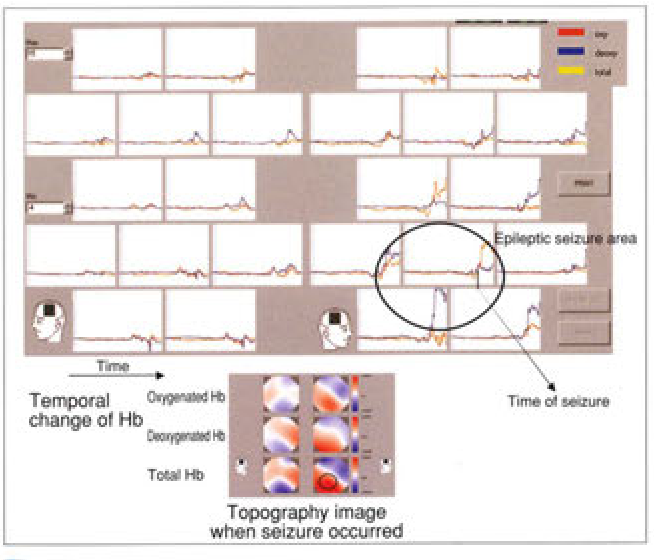


Fig. 5
Example of Epileptic Seizure Measurement by Optical Topography (Continuous mode)

3. Development of Related Techniques

The following sections present related techniques developed for improving functions of the optical topography system targeting clinical applications.

3.1 High-precision optical measuring technique

To measure faint change of Hb concentration according to brain activity, the optical topography requires high measuring accuracy. To catch change of blood flow in the brain cortex of adult, distance from the light source to measurement point needs to be more than 30mm[1]. When collecting light by a fiber with diameter of 1mm and incident light quantity of 2mW, measuring light volume would be about 1pW even if using an optimum fiber. Change of transmission light quantity caused by change of optical absorption due to cerebrum function activity is normally about several percent. Therefore, the minimum detectability needs to be about 10fW (1% of 1pW) at the detector.

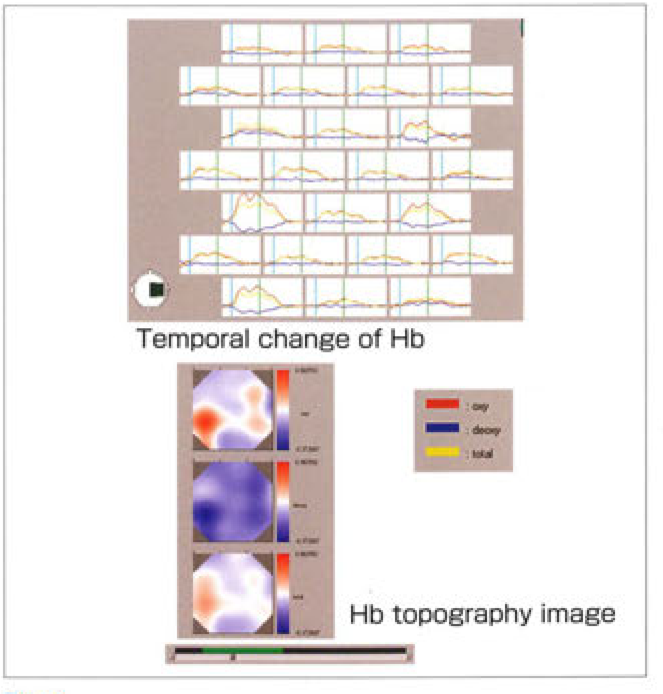


Fig. 6
Example of Motor Area Measurement by Optical Topography (Integration mode)

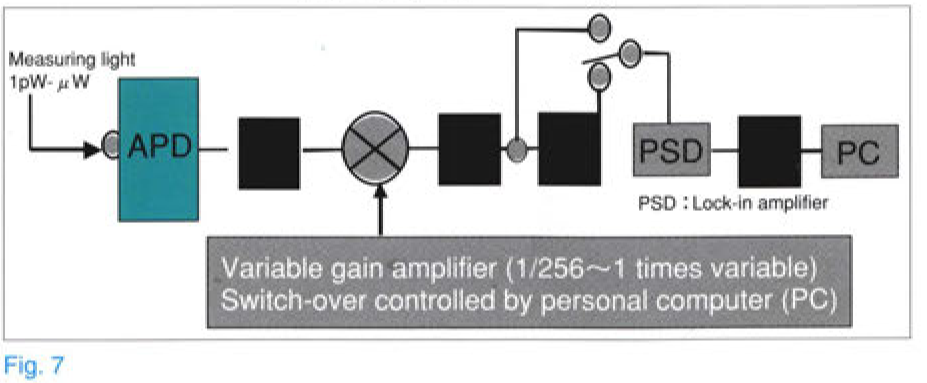


Fig. 7
Composition of Wide Dynamic Range Measuring Circuit

At the same time, if expanding the applicable range from adults to infants, measuring light quantity increases up to about 1μ W that is 1000 times of that for adults. This requires that noise at input must be 10fW or less in the optical topography measuring system, and further incident light quantity must be measurable in a range of 1pW - 1μ W. To realize this, this system not only uses the high-sensitive APD (Advanced Photodiode) elements for the detector but also the PC controls the variable gain multi-stage amplifier to set appropriate signal level, and then the lock-in amplifier extracts signals (Fig. 7). This allows sufficient dynamic range to be obtained in a range of incident light quantity 1pW - 1μ W and performance measurable from adults to new born babies to be obtained.

3.2 High-sensitive probe system

The optical topography probe collects measuring light from the patient body surface and transmits it to the detector of system main body. Therefore, it requires not only high detection efficiency but also performances listed below from a functional standpoint:

(1) Less signal change due to patient motion
(2) Less burden to the patient when attached, and no discomfort when attached for a long time
(3) Attachable easily and in a short time

This system uses a bundled type fiber which element is multi-ingredient glass highly flexible and high in transmission efficiency in a near-infrared range to satisfy these requirements. The bundled fiber satisfies the requirements above since the diameter of element wires is very fine (about 30 - 50μ m) and flexible allowing it to be easily bent and durable. Also, it can compose any size of fiber probe by bundling element wires without losing flexibility according to measuring conditions.

In addition, highly efficient measurement of faint light emitted from the surface of head needs high light-gathering efficiency and low transmission loss. Light emitted from the living body becomes nearly isotropic dispersion light at 2~3mm apart from the incident point due to strong dispersion of living body (dispersion factor about 1.0/mm). Therefore, light detection efficiency of the optical topography (detection distance 2~3cm) is nearly proportional to the product of effective detection area and detection solid angle. Effective detection area of the bundled fiber is proportional to fiber filling rate × core rate × overall diameter of fibers (number of element wires). Fiber filling rate is about 60% of maximum filling. Where, overall diameter needs to be an interval of hair roots (about 2mm) or less to contact the tip with the scalp avoiding effects of hairs. Therefore, to improve optical detection efficiency, core filling rate and fiber detection solid angle, i.e. NA (number of apertures) of fiber need to be improved. In this system, we developed a bundled fiber made of high refractive index multi-ingredient glass fiber, which NA with two points above improved is 0.87, and obtained high detection efficiency.

At the same time, we improved touch feeling to the scalp by covering the optical fiber with the plastic probe holder, and realized the optimum tip shape to reduce hairs to be caught. In addition, we adopted a compression mechanism for the patient body surface by optimally adjusted spring to avoid excessive compression to the patient (Fig. 8).

3.3 Image display system

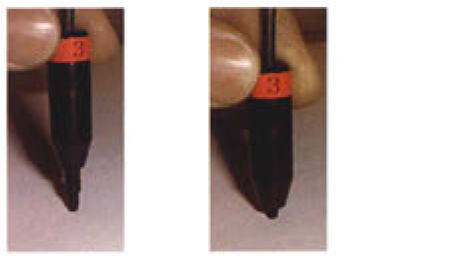
To effectively utilize functional information obtained by the optical topography in clinical applications, we developed the following Hb signal display system for optical topography to support diagnosis.

(1) Hb temporal change map

It displays temporal change of three types of Hb at each measuring point allowing change of Hb due to neural activity near the measuring point to be observed as a temporal progress. By evaluating temporal change of the graph in detail, the state of blood flow and metabolism can be diagnosed in detail. It is the most fundamental data of Hb display and uses mM · mm that is an index of Hb change as a scale.

(2) 2-dimentional Hb topography image display

This display represents distribution of Hb change at each measuring point at the same time as an image, and an interval between measuring points is interpolated by the approximate function connecting each measurement point. Usually increase from the initial state is displayed in red, while decrease in blue. This allows the center of reaction and distribution characteristics to be exactly judged. Also temporal change of this topography can be displayed in the cine mode allowing dynamic change of blood flow and metabolism to be caught.



A part touching scalp is a spring-loaded structure to stably contact the head with the most suitable pressure

Fig. 8
Tip of Probe

(3) 3-dimentional topography image display

The optical topography data has been confirmed to reflect blood distribution on the brain surface. In human being, it has been known that functions are distributed to regions according to its structure on the brain surface (functions localize). To exactly judge brain activity and perform neurological diagnosis with the optical topography, the relationship between surface structure of cerebrum and optical topography data needs to be spatially caught. For example, the typical functional imaging system PET realizes this by superimposing a tomogram onto a MRI image 3-dimentionally. The optical topography system creates a 2-dimentional function image of brain surface. Therefore, it needs development of "Means to measure position of measuring probe" and "Means to display 2-dimentional image synthesized onto 3-dimentional image" to display a 2-dimentional optical topography image superimposed on a 3-dimentional MRI image. We developed the following means:

(A) Navigation system for the optical topography system to measure coordinates of the probe set to the head surface 3-dimentionally and obtain positional relationship between the patient and MRI image

(B) 3-dimentional displaying system to display an optical topography image synthesized on a MRI or CT 3-dimentional image.

Fig. 9 shows composition of the navigation system. It measures position coordinates of the probe set to the patient head using the magnetic sensor and superimposes this on a MRI image on a computer.

Also, the optical topography measures Hb change on the brain surface 20mm deep from the scalp, so coordinates of the measuring probe differ from the measuring area 3-dimentionally. Therefore, in the optical topography 3-dimentioanl display system, each measuring signal is supposed to come from the brain surface just under the intermediate point between probes according to optical dispersion characteristics of living body. Thus, the topography functional image is superimposed on the brain surface of MRI image just under the intermediate point between probes.

Fig. 10 is an example for an optical topography image of hand motion displayed on a MRI image. As shown in this example, active area of the optical topography image displayed in red agrees with the motor area on the MRI image that is currently well known. Thus we can exactly catch functional activity of the brain by displaying positional relationship between brain structure and optical topography image.

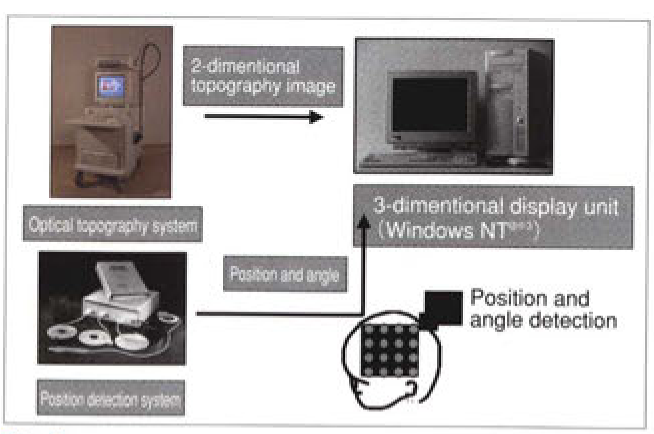


Fig. 9

Optical Topography 3-dimensional Display System

4. Clinical Measurement Data

The following shows examples of recent studies for clinical applications of the optical topography.

(1) Newborn baby brain function measurement

Human brain function has plasticity, if a part of it failed, to compensate the failure. For example, even if auditory sense failed and speech development has some difficulty, speech function failure and delay of mental development due to this trouble can be prevented if an appropriate action is taken in its early stage. In the other cases of various functional failures, if an appropriate action is taken in its early stage, it greatly benefits them to grow after that. Therefore, diagnosis of functional failure in its early stage after birth has been attempted; however, there has been no means of less invasive and exact diagnosis. The optical topography is suitable for measurement of newborn babies since it is noninvasive and less restraint, further it can simply measure brain function. Therefore, the optical topography is expected to apply to brain function diagnosis of newborn babies.

An exclusive probe suitable for brain measurement of newborn babies shown in Fig. 11 has been developed, and optic area reaction of newborn babies against photo stimulus has been measured using this device.

Fig. 10

Example Display of 3-Dimentional Image

(2) Simultaneous measurement with MRI

The optical topography system not only can perform noninvasive and simple brain function measurements but also has less interference with the other measurement means as a feature of optical measurement. Thus it is expected that higher diagnostic information could be obtained by simultaneously using the other measurement means integrated with the optical topography system. For example, integration with measuring means such as EEG, MEG, PET, MRI, etc. is considered. Fig. 12 shows a result of simultaneous measurement with fMRI using high magnetic field MRI and the optical topography system, and functional signals of both devices on hand motion of the patient show very good correlation. As above, it also suggests possibility of high precision optical topography even in the high magnetic field MRI, and indicates possibility of advanced diagnosis by integrated measurements.

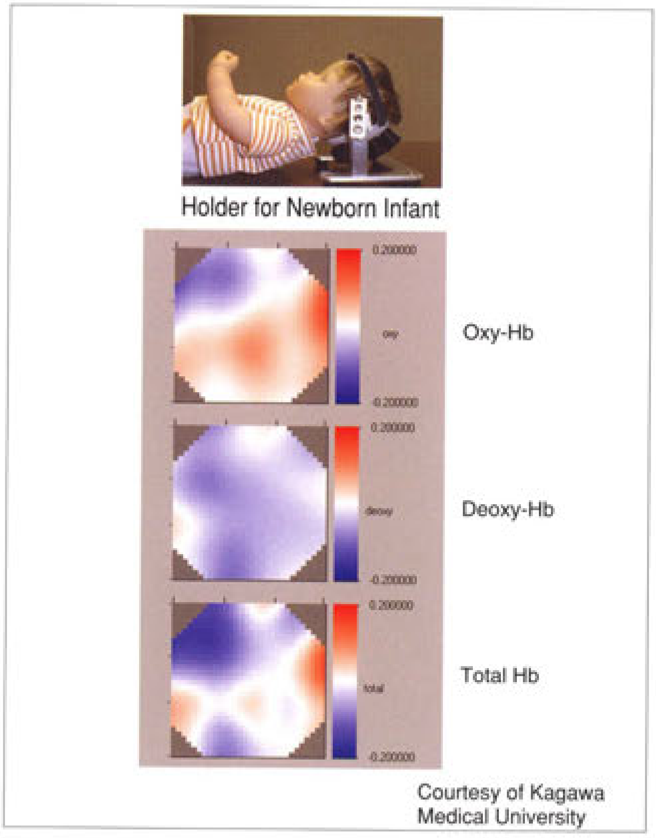


Fig. 11
Visual Response of Newborn Infant

5. Conclusion

We developed the optical topography system ETG-100 targeting clinical applications. We are not only evaluating its clinical efficacy but also proceeding technical development for realizing higher functionality and higher performance. In the future, it is strongly requested to develop an optical topography capable of more precise brain function measurement as well as to develop more friendly system for clinicians and patients as users. We would like to widely accept requests of clinicians and patients and proceed development of a higher performance and more friendly optical topography system.

※1 Optical Topography is a trademark of Hitachi Ltd., Japan.
※2 WindowsNT is a trademark of Microsoft Corp., U.S.A.

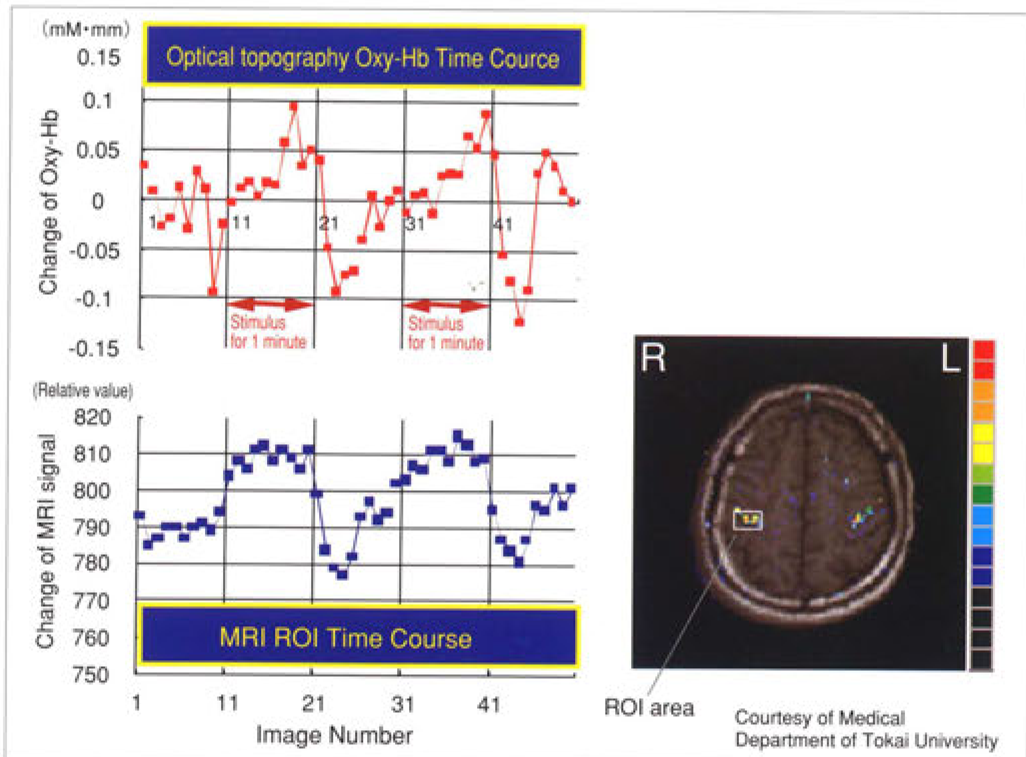


Fig. 12
Example of Simultaneous Measurement with MRI