Abstract. Near infrared spectroscopic topography (NIRS) is widely recognized as a noninvasive method to measure the regional cerebral blood volume (rCBV) dynamics coupled with neuronal activities. We analyzed the rCBV change in the early phase of epileptic seizures in 12 consecutive patients with medically intractable epilepsy. Seizure was induced by bemegride injection. We used eight-channel NIRS in nine cases and 24 channel in three cases. In all of the cases, rCBV increased rapidly after the seizure onset on the focus side. The increased rCBV was observed for about 30–60 s. The NIRS method can be applied to monitor the rCBV change continuously during seizures. Therefore, this method may be combined with ictal SPECT as one of the most reliable noninvasive methods of focus diagnosis. © 2000 Society of Photo-Optical Instrumentation Engineers. [S1083-3668(00)00103-9]

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and from 10 to 20 s after the onset, which generated 20 data for each time window. This pair of data was compared by $t$-test and a significant blood volume increase was determined when it showed $p < 0.001$ significance.

Because of the load to the patients, the seizure induction procedure was done only once for a patient.

### 3 Results

Three representative cases listed in the Table 1 are described below.

**Case 4:** A 40-year-old female with intractable complex partial epilepsy underwent ictal SPECT along with NIRS monitoring. Eight-channel NIRS measurement (four on each side, symmetrically) was done with 10 probes implanted on the head shell [Figures 1(A) and 1(B)]. Seizure activity was observed by depth EEG recorded with depth electrodes implanted in the right hippocampus. After the seizure onset, the rCBV increased in the right temporal region, lasting for 30 s and returning to the resting level [Figure 1(C)]. Ictal SPECT (Figure 1, inset) showed rCBV increase in the right temporal lobe, compatible to the NIRS findings. A seizure focus was confirmed in the right medial temporal lobe by depth EEG recordings. The right temporal lobectomy was done, releasing her from seizures.

**Case 12:** An 8-year-old girl with intractable epilepsy was transferred to our clinic for surgical intervention. Her seizure started with tingling sensation in the right arm sometimes fol-

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**Table 1** Cases with intractable epilepsy studied with NIRS and ictal SPECT. The columns named "EEG," ictal "SPECT," and "NIRS" indicate the side (R: right; L: left; N: not definite) of the side of suspected focus in each modality. "sg channels" indicates a number of channels that showed significant rCBV increase during seizures.

<table>
<thead>
<tr>
<th>Case</th>
<th>Age</th>
<th>Sex</th>
<th>Focus</th>
<th>EEG</th>
<th>Ictal SPECT</th>
<th>NIRS</th>
<th>Total channels</th>
<th>sg channels</th>
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<tr>
<td>1</td>
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<td>R</td>
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<td>4</td>
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<tr>
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<td>L</td>
<td>L</td>
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<td>4</td>
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<td>4</td>
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<td>R</td>
<td>R</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
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<td>40</td>
<td>m</td>
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<td>L</td>
<td>L</td>
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<td>3</td>
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<tr>
<td>6</td>
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</tr>
<tr>
<td>7</td>
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<td>R</td>
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<tr>
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<td>N</td>
<td>L</td>
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<td>7</td>
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<tr>
<td>11</td>
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<tr>
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<td>L</td>
<td>L</td>
<td>24</td>
<td>4</td>
</tr>
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</table>
followed by secondary generalization. Under EEG and NIRS monitoring, a seizure was induced with bemegride injection. A seizure began in the left parietal area. Ictal SPECT showed the hyperperfusion in the left postcentral area. NIRS showed rCBV increase in the same area as that in ictal SPECT immediately after the seizure onset lasting for about 25 s. Figure 2(A) shows the hyperperfusion in the left postcentral area [Figure 2(A)]. NIRS showed rCBV increase in the same area as that in ictal SPECT immediately after the seizure onset lasting for about 25 s. Figure 2(B) and 2(C) show the time courses of [Hb total] at the focus site and its control on the opposite side. A letter at the left of each column indicates the time after bemegride injection. The rCBV began to increase 5 s after spike discharge (at 48 s) in the left parietal area. The subdural electrodes demonstrated the seizure spike onset in the left postcentral area which supported the above findings. The small corticectomy (20 mm by 20 mm in size) was done in the left postcentral area resulting in 80% seizure reduction after the surgery.

Case 11: This is a 27-year-old female with medically intractable epilepsy. Her seizures usually began with simple partial seizures with tingling sensation in her right arm, followed by clonic seizures of her right arm. Secondary generalizations were sometimes observed. MEG revealed T2-high area in the left postcentral gyrus, suggesting cortical dysplasia (Figure 3 insets). MEG showed spike dipoles gathering in the abnormal area in MRI. The video-EEG monitoring showed that spike burst discharges began in the left central area before the clinical seizures. Ictal SPECT was performed with NIRS.
The NIRS probes were placed on bilateral postcentral areas covering the region with abnormal MRI. A seizure occurred with the EEG and clinical patterns similar to the habitual ones after bemegride injection. The ictal SPECT showed a hyperperfusion area in the left postcentral region compatible to the MRI and MEG findings. The NIRS recording showed a steep increase of rCBV in the left postcentral area immediately after the EEG spike train onset (Figure 3). The increased rCBV remained for 30 s and returned to the preictal state. Subdural grid electrodes revealed spike bursts beginning in the left postcentral area prior to the clinical seizures.

The above findings suggested the focus in the left postcentral gyrus. The parietal region including the focus was resected making the patient almost freed from seizures.

4 Summary of Cases
The results of NIRS measurement in 12 cases are summarized in the Table 1. The seizure foci were confirmed by the EEG and MRI findings. Ictal NIRS were measured along with the ictal SPECT in all the cases. Ictal SPECT demonstrated distinct hyperperfusion in the areas surrounding the seizure focus in seven cases, whereas no obvious hyperperfusion was found in four cases and one showed an increase on the contralateral side. The NIRS demonstrated rCBV increase in the region of the focus in all the cases. The increase began within 2–5 s after the seizure onset confirmed by intracranial EEG, and it lasted for 45 ± 12.3 s. In cases 9 and 10, rCBV increase began on the focus side and spread to the other side within 10 s.

5 Discussion
The near infrared light projected into the brain penetrates and reflects randomly in the tissue. The near infrared light measured at a certain distance represents the absorption by quasisemicircular tissue in the brain connecting the transmitting and receiving probes. The depth of the measuring point depends on the distance between the transmitting and receiving probes. It was reported that NIRS signal mainly reflected the absorption at the depth of 1.2 – 2.0 cm below the scalp when the interprobe distance was 27 mm. As the human cerebral cortex usually lies about 10–20 mm below the scalp, the appropriate interprobe distance should be 25–30 mm to measure the activities in the superficial cortex. The interprobe distance was therefore determined as 30 mm in the present study.

The tight coupling between the neuronal activity and the rCBV increase has been established and used in the functional mapping with PET, SPECT, and fMRI. Watanabe et al. reported that the rCBV increase was demonstrated by NIRS in the pericentral region during finger tapping task. The activity-coupled rCBV increase is also expected during epileptic seizures. Horsley first described ictal focal hyperperfusion by the direct visual inspection of the brain during seizures. The PET unexpectedly taken during seizures confirmed this. Ictal SPECT is the first well-planned examination to reveal the ictal hyperperfusion. Rowe et al., Newton et al., and Stefan et al. described the ictal hyperperfusion by HMPAO-SPECT. They demonstrated obvious hyperperfusion in epileptogenic area when HMPAO was injected during a seizure or within 30 s after the seizure termination. In this study, we observed compatible ictal rCBV increase also with NIRS method.

It should be noted that NIRS measures only the phenomenon in the superficial cortex of the brain making it ideal for neocortical epilepsy. It is particularly important when we evaluate the results in medial temporal epilepsy. Ictal SPECT demonstrated that, in most of the cases with medial temporal epilepsy, rCBV increased in the ipsilateral lateral temporal cortex as well as in the medial temporal structures supposingly according to the seizure spread to these areas. The seizure spread is usually detectable only by intracranial subdural electrode EEG but not by scalp EEG. This supports the feasibility of the NIRS and its advantage over scalp EEG even in the medial temporal epilepsy.

6 Conclusion
In search for noninvasive methods for focus diagnosis, we reached a conclusion that the combination of ictal SPECT and NIRS is one of the most reliable techniques to visualize the hemodynamic changes during seizures. The ictal SPECT offers the static tomographic images of rCBV and the NIRS enables us to observe the rCBV continuously. If combined, these two methods may support each other.

References

290 Journal of Biomedical Optics  July 2000 Vol. 5 No. 3