Chapter 62
Monitoring of Hemodynamic Change in Patients with Carotid Artery Stenosis During the Tilt Test Using Wearable Near-Infrared Spectroscopy

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Abstract Transient ischemic attack (TIA) is a major complication in patients with carotid artery stenosis. Patients with severe stenosis sometimes complain of orthostatic dizziness, such as syncope. The purpose of this study was to examine the usefulness of near-infrared spectroscopy (NIRS) for evaluating cerebral circulation in patients with carotid artery stenosis during head-up tilt test (HUTT). Fourteen patients with carotid artery stenosis and nine normal control subjects participated. In addition to blood pressure monitoring, hemoglobin (Hb) values (oxy-Hb, deoxy-Hb, and total Hb) were recorded by a wearable NIRS instrument with a high time resolution during HUTT. Oxy-Hb, which decreased initially when the test table was elevated, subsequently increased in normal volunteers and patients with carotid artery stenosis and did not differ significantly between the two groups. However, the oxy-Hb reduction in the carotid artery stenosis group (-0.02 ± 0.03 a.u.) at 30 s after elevation of the table was significantly larger than in the normal group (0.02 ± 0.02 a.u., $P < 0.01$). Our results indicate that oxy-Hb reduction in patients with carotid artery stenosis may be related to orthostatic dizziness. We concluded that NIRS monitoring is useful for evaluating cerebral autoregulation in patients with severe carotid artery stenosis.

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62.1 Introduction

Transient ischemic attack (TIA) is a major complication in patients with carotid artery stenosis, affecting approximately 7 %/year of patients with severe carotid artery stenosis. Patients with severe stenosis also sometimes complain of orthostatic dizziness, such as syncope, though the reason for this is unclear. The baroreflex is the most important regulatory mechanism in the short-term control of circulation, and some reports indicate that baroreflex sensitivity (BRs) of patients with carotid artery stenosis is low, compared with normal subjects [1–3]. The head-up tilt test (HUTT) has been used to examine physiological events during graded orthostatic challenge in individuals with significant handicap owing to neurocardiogenic syncope (NCS).

Near-infrared spectroscopy (NIRS), a noninvasive optical method, utilizes the characteristic absorption spectra of hemoglobin (Hb) in the near-infrared range to provide information on hemodynamic changes and cerebral blood oxygenation changes. However, the influence of postural stresses on cerebral circulation in patients with carotid artery stenosis is unclear.

We hypothesized that impaired cerebral oxygenation may be related to postural symptoms, and in this study we investigated whether NIRS monitoring would be a suitable approach to examine whether patients with carotid artery stenosis and healthy volunteers show differential hemodynamic changes during HUTT.

62.2 Methods

We investigated 14 patients with carotid artery stenosis (10 men and 4 women; mean age, 69.4 ± 7.2 years) and nine normal control subjects (5 men and 4 women; mean age, 26.0 ± 1.1 years). A HUTT procedure was started by having the patient lie supine on a tilt table while connected to a precordial lead electrocardiogram and an automated intermittent oscillometric blood pressure monitor. Each subject lay in the supine position on the tilt table for at least 15 min before the procedure. In the first step, the table was elevated to 30° during 10 min. Then, it was elevated to 70° during 10 min. We measured the concentration changes of each Hb in the bilateral frontal lobe using a newly developed NIRS device (Pocket NIRS, Hamamatsu Photonics K.K., Japan) (Fig. 62.1). This device employs a wireless communication system (Bluetooth®) instead of optical fibers, so that the subject's movement is not constrained. In the present study, we used continuous-wave NIRS. Measurement of continuous-wave NIRS is dependent on the modified Beer-Lambert law, which includes optical pathlength (PL) as an essential parameter. Therefore, we believe that it is better to used arbitrary units rather than micro molar. This study was approved by the Committee for Clinical Trials and Research at Nihon University School of Medicine and Sagamihara Kyodo Hospital. All patients or their relatives gave written informed consent.

Fig. 62.1 The NIRS system uses LEDs of three different wavelengths (735, 810, and 850 nm) as light sources and one photodiode as a detector; it has two channels. The total weight of the controller and probes is only 160 g. The sampling rate was 61.3 Hz (i.e., the sampling time was about 16.3 ms)

62.3 Results

There was no significant difference in systemic circulation change during HUTT between the two groups. In normal volunteers, oxy-Hb decreased initially after the table was elevated. However, it rapidly recovered, then remained constant (Fig. 62.2a). In contrast, oxy-Hb of patients with carotid artery stenosis decreased and did not subsequently recover to the initial level (Fig. 62.2b). The oxy-Hb reduction in the carotid artery stenosis group at 30 s after elevation of the table was significantly larger than that in the normal group at 30° ($P<0.05$) and at 70° ($P<0.01$) (Fig. 62.3a). Deoxy-Hb slightly increased during HUTT in the carotid artery stenosis group, but was not significantly different from that of normal volunteers (Fig. 62.3b). When the tilt table was brought back to the supine position, each Hb concentration returned to baseline.

62.4 Discussion

Static cerebral circulation in patients with carotid artery stenosis has been evaluated using single-photon emission computed tomography (SPECT) [4] and positron emission tomography (PET) [5]. However, these techniques cannot measure dynamic changes in cerebral blood flow (CBF). On the other hand, NIRS can measure dynamic changes in both CBF and cerebral metabolism. Therefore, in the present study, we examined whether NIRS monitoring is suitable for studying hemodynamic changes in patients with carotid artery stenosis during HUTT.

We observed a sustained reduction of oxy-Hb during HUTT in patients with severe carotid artery stenosis, and this might be associated with orthostatic

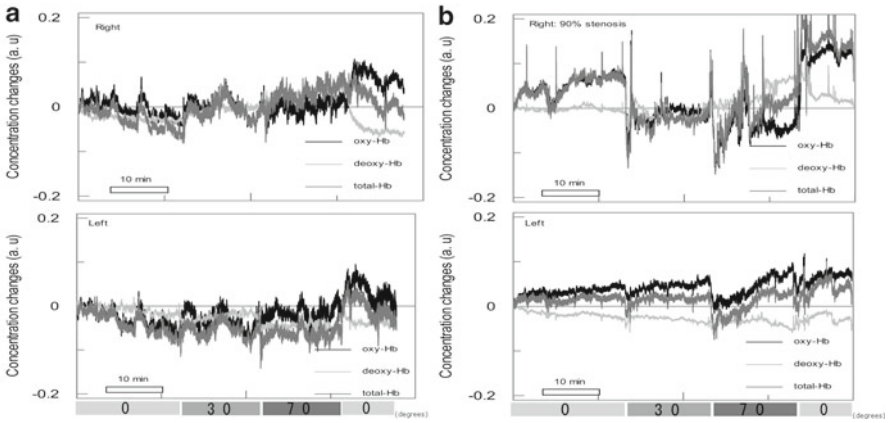

Fig. 62.2 Hb concentration changes during HUTT in normal volunteers (**a**, *left*) and patients with carotid artery stenosis (**b**, *right*). The ordinates indicate concentration changes of oxy-Hb (*black*), deoxy-Hb (*light gray*), and total Hb (*dark gray*) in arbitrary units (a.u.). The abscissa indicates time (min); *horizontal bars* indicate 10 min. The *horizontal bars* indicate the time schedule of HUTT

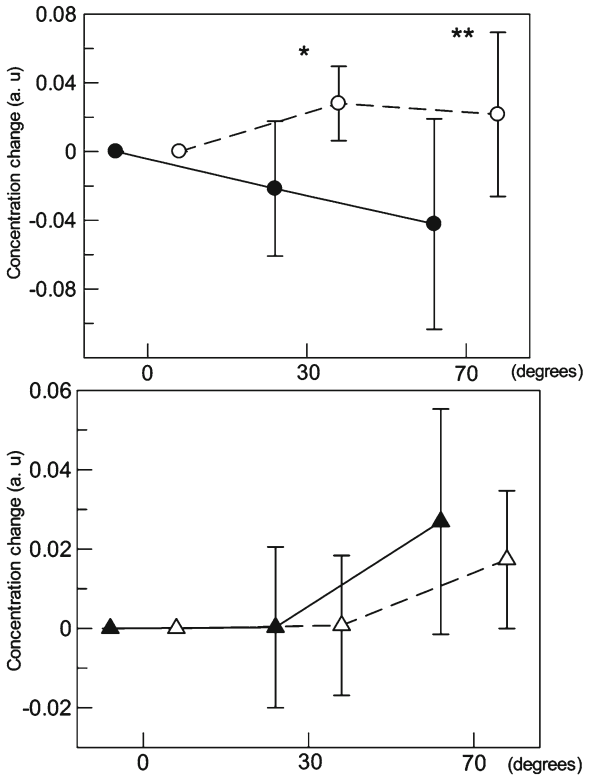

Fig. 62.3 (**a**) Change of oxy-Hb during HUTT in normal volunteers and patients with carotid artery stenosis. *Open circles* ($n=9$) indicate the mean value of normal volunteers; *solid circles* ($n=14$) indicate the mean value of patients with carotid artery stenosis. (**b**) Change of deoxy-Hb during HUTT in normal volunteers and patients with carotid artery stenosis. *Open triangles* ($n=9$) indicate the mean value of normal volunteers; *solid triangles* ($n=14$) indicate the mean value of patients with carotid artery stenosis. The ordinates indicate concentration changes of Hb in arbitrary units (a.u.)

dizziness. On the other hand, NIRS monitoring showed only a transient reduction of oxy-Hb in patients with mild or moderate carotid artery stenosis and in healthy volunteers during postural stresses, followed by a rapid recovery. None of these patients or volunteers had experienced orthostatic dizziness.

It is important to note that we examined only a relatively small number of patients and normal volunteers. Also, it is not yet clear whether NIRS parameters measured in the frontal lobe fully reflect hemodynamic changes in the cerebral hemisphere. Nevertheless, our results indicate that the present NIRS system, which is compact enough to attach to patient's clothes and is equipped with telemetric data transfer, is suitable for investigating and evaluating cerebral autoregulation in patients with severe carotid artery stenosis during HUTT.

62.5 Conclusions

We concluded that NIRS monitoring is useful for evaluating cerebral circulation and autoregulation in patients with severe carotid artery stenosis.

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