

Functional near-infrared spectroscopy study on primary motor and sensory cortex response to clenching

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ABSTRACT

The purpose of this study was to elucidate the influence of clenching and clenching intensity on oxygenated hemoglobin (OxyHb) levels in regional cerebral blood flow as an indicator of brain activity in the primary motor and sensory cortices. Functional near-infrared spectroscopy (fNIRS) was used to minimize the effect of clenching-associated muscle activity in eight healthy subjects. Subjects were required to clench at 20%, 50% and 80% of maximum clenching force. To minimize the effect of temporal muscle activity on the working side of the jaw, the fNIRS probes were positioned contralaterally, in the left temporal region. Activation of the primary motor and sensory cortices with clenching was noted in all subjects, irrespective of intensity of clenching. A significant increase was observed in OxyHb in the primary motor cortex between at 80% and both 20% and 50% clenching intensity. In the primary sensory cortex, OxyHb showed a significant increase between all levels of clenching intensity. The results suggest that clenching elicits activation of both the primary motor and sensory cortices, and that intensity of clenching influences activation levels in the brain.

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The relationship between brain activity and the stomatognathic system has been studied using positron emission tomography [21] and functional magnetic resonance imaging (fMRI) [12,26,31]. However, it is considered difficult to obtain sufficient data during jaw movement with these techniques as the concomitant head motion creates artifacts on the images.

On the other hand, functional near-infrared spectroscopy (fNIRS) is a powerful, non-invasive imaging system. It offers many advantages, including compact size, no need of specially equipped facilities, the potential for real-time measurement and, especially, the ability to distinguish signals, even when there is background muscular activity.

However, few studies have carried out a detailed investigation into the relationship between temporal brain function and occlusion and mastication, due to the potential for corruption of data by the undesirable effect of muscular activity associated with jaw movement such as that of the temporal muscles [12]. In particular, the relationship between brain activity and different type and strength of jaw movement, including mastication and clenching, remains to be clarified.

The purpose of this study was to elucidate the influence of clenching and clenching intensity on oxygenated hemoglobin

(OxyHb) levels in regional cerebral blood flow (rCBF) as an indicator of brain activity in the primary motor and sensory cortices under conditions designed to minimize the effect of associated muscle activity using fNIRS.

This study was approved by the Ethics Committee of Tokyo Dental College (No. 164) and was conducted in accordance with the Declaration of Helsinki (Edinburgh Revision).

Subjects consisted of eight healthy right-handed male volunteers with no subjective or objective symptoms of problems of the stomatognathic system or cervicofacial region (age, 35.2 ± 9.0 yrs). Informed consent was obtained from all subjects in accordance with institutional guidelines.

The canine [32] region was considered suitable for observation of brain activity associated with clenching. Accordingly, a bite block equipped with an occlusal force sensor (KLC-60KA-S19; Frontier Medic, Co. Ltd., Japan) was prepared to measure clenching at the position where the right upper and lower canine cusps came into contact. Intensity of clenching was shown on a display and feedback was provided to the subjects. Intensity was set at 20%, 50% and 80% of maximum clenching force. Each subject was required to perform clenching on the bite positioner at each of these three intensities after first establishing maximum clenching intensity.

All tasks were performed using a block design [12,30]. Each subject was required to perform the clenching task twice at each of the set intensities, but in random order, as instructed by the examiner. At the start of the experiment, the subject was required to sit

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quietly until OxyHb registered no change on the fNIRS. Next, the subject was required to rest 20 s and then commence clenching for 20 s. After clenching, the subject then rested for 20 s. The subject then proceeded to the next clenching task following the same 20-s rest, 20-s clenching, 20-s rest pattern. This meant that each block lasted a total of 60 s. The subjects participated in a fNIRS trial before measurements were conducted. In setting the head position, the subject was instructed to sit with the mouth slightly open with no tension in the mandible. This was taken as the standard position for measurements. The number of clenching tasks at each intensity was limited to two in order to avoid the effects of sensory fatigue and adaptation [19]. The subjects sat in a quiet room and observed their performance on a bite pressure meter.

Activity of the right masseter muscle during clenching was determined by electromyography (BioLog DL-2000, DL-141 S&ME, Inc., Japan). The temporal muscles have been shown to exhibit spontaneous activity, even when the mandible is not moving [16], so activity of the left temporal muscle was also measured by an electromyograph attached anteriorly to the fNIRS probes. In addition, the subjects were trained to clench without activating this muscle, as much as possible.

fNIRS (NIRStation OMM-2001, SHIMAZU Co. Ltd., Japan) was used to determine rCBF in the primary motor and sensory cortices during clenching. The central sulcus was determined by drawing a line from the Nasion to the Inion. Next, a point 2 cm posterior to the midpoint of this line was taken as the top of the central sulcus. Then, a line was drawn between a point 5 cm superior to the porus acusticus externus to the point 2 cm posterior of the midpoint of the Nasion/Inion line. This was taken as indicating the position of the central sulcus. The probes were then positioned so as to cover the areas anterior and posterior to the central sulcus according to the method of Greenberg [7]. The spectroscopy's 13 emitters and 12 detectors were arranged alternately in a lattice pattern, at a distance of 30 mm between them, to form 40 source–detector pairs on a helmet for positioning on the subject's head. According to Hiraba et al. [8] human ipsilateral temporal muscles become active during lateral movement. Therefore, artifacts due to temporal muscle activity on the working side of the jaw can cause serious problems. In order to avoid this, the fNIRS probe helmet was positioned contralaterally, in the left temporal region.

The accuracy of the probe positions for identifying active sites in the brain was evaluated in three of the subjects (Fig. 1). The probe positions were overlaid on MRI (Symphony 1.5 T; Simens, T1-weighted sequences, 1-mm slice) anatomical surface images of each individual using a 3D magnetic space digitizer (FASTRAK, Polhemus, USA) and a specific software (Fusion, SHIMAZU Co. Ltd., Japan) [20,24].

Hoshi et al. suggested that, in contrast to total hemoglobin (TotalHb) and deoxygenated hemoglobin (DeoxyHb), the direction of change in OxyHb was always the same as that of change in rCBF. As a result, OxyHb has been proposed as the best indicator of change in rCBF in cognitive studies with NIRS [10]. The OxyHb data for the 10-s period commencing 5 s after commencement of clenching at each intensity was averaged between all subjects. Next, a statistical analysis was performed using the Paired t-test (SAS 9.1, SAS Institute Japan, Inc., Japan. $p < 0.05$).

We confirmed measurement position on the MRI surface image. The portion of the probe anterior to the central sulcus was positioned over the precentral gyrus, corresponding to the primary motor cortex, and the portion posterior to the central sulcus was positioned over the postcentral gyrus corresponding to the primary sensory cortex (Fig. 1). Fig. 2 shows the time course of changes in OxyHb, DeoxyHb and TotalHb levels in one subject. A tendency toward an increase in OxyHb was observed in the primary motor and sensory cortices with clenching in all subjects, irrespective of

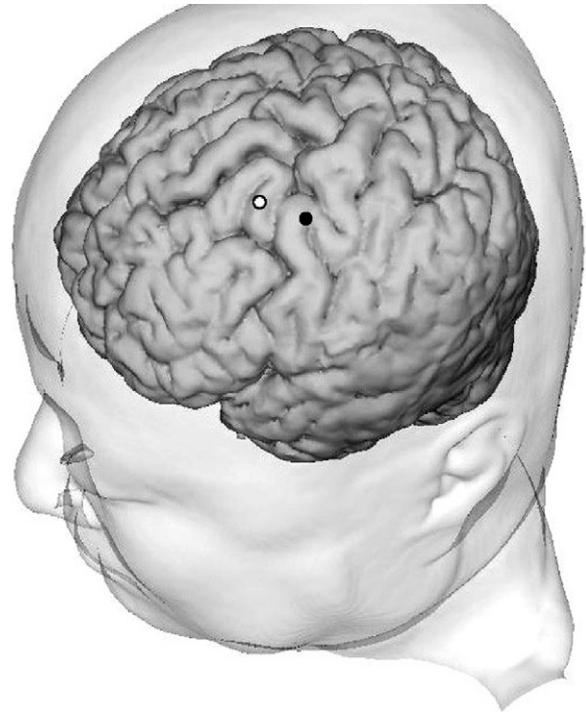


Fig. 1. Measurement positions on MRI surface image. The portion of the probe anterior to the central sulcus was positioned over the precentral gyrus, corresponding to the primary motor cortex (White dot), and the portion posterior to the central sulcus was positioned over the postcentral gyrus corresponding to the primary sensory cortex (Black dot).

clenching intensity. Fig. 3a and b shows these changes in OxyHb levels in the cerebral cortex. A significant increase was observed in OxyHb in the primary motor cortex between at 80% and both 20% and 50% clenching intensity (Fig. 3a). A significant increase was observed in OxyHb in the primary sensory cortex between all intensities measured (Fig. 3b). Moreover, electromyographic recordings revealed a significant increase in activity in the right masseter muscle between at 20% and both 50% and 80% clenching intensity (Fig. 3c). Finally, we observed increases in OxyHb in the prefrontal cortex during clenching when clenching intensity was over 50%, suggesting that clenching indicated activation of the prefrontal cortex.

The positioning of the fNIRS probe arrangement was evaluated using a 3D image. The portion anterior to the central sulcus was positioned over the precentral gyrus, corresponding to the primary motor cortex; the portion posterior to the central sulcus was positioned over the postcentral gyrus, corresponding to the primary sensory cortex. The findings of this study are consistent with those of an fMRI study by Tamura et al. [31], in which it was found that the primary motor and sensory cortices showed marked activation with clenching. The cortical masticatory area in the primary motor cortex, which directs jaw movement, is located anterior to the central sulcus in the external cerebral hemisphere. However, the results of an MEG study by Sekine et al. [27] indicated that the bases of the bilateral central sulci, corresponding to the 3a areas in the primary sensory cortices, were responsible for the initial processing of mechanical information from the periodontal ligament when tactile stimulation was applied to the upper and lower central-incisors. This suggests that the choice of the primary motor and sensory cortices for measurement of brain activity in this study was appropriate.

A tendency toward an increase in OxyHb in the rCBF was observed contralateral to the clenching side in the primary motor

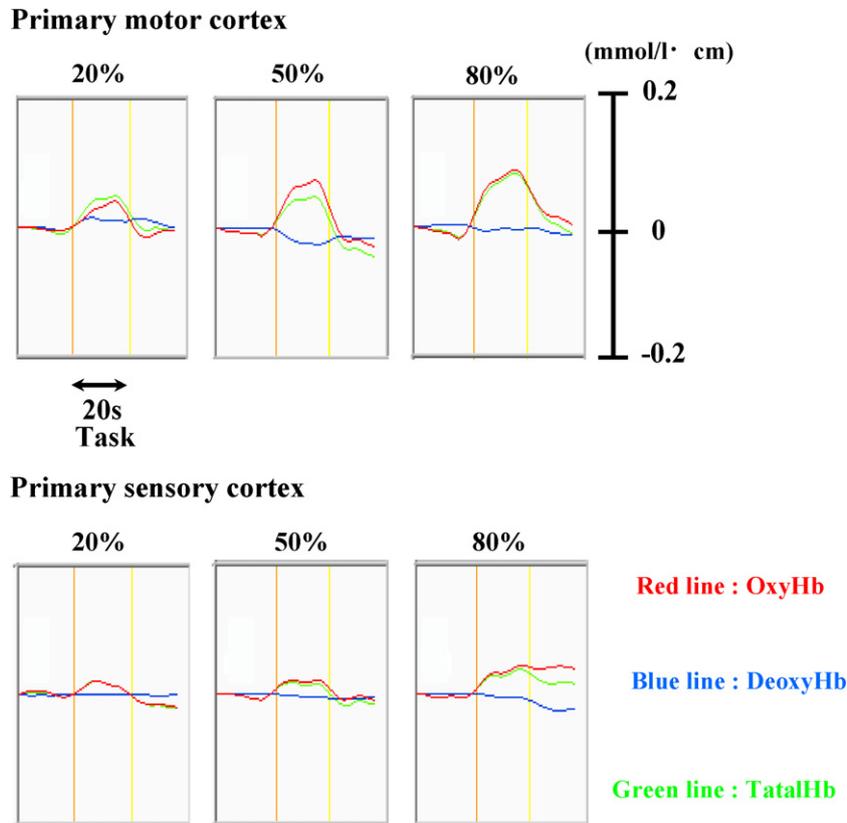


Fig. 2. Changes in OxyHb, DeoxyHb and TotalHb levels in the primary motor cortex and primary sensory cortex response to clenching. A tendency toward an increase in OxyHb was observed in the primary motor and sensory cortices with clenching in all subjects, irrespective of clenching intensity.

and sensory cortices. An increase in OxyHb and a decrease in DeoxyHb in rCBF are usually observed in fNIRS measurement of cerebral activation [10,33]; whereas, with blood flow in the clenching muscle itself, a decrease in OxyHb and an increase in DeoxyHb are usually observed [29]. Therefore, data (rCBF change) resulting from temporal muscle activity could be excluded from the analysis easily. Many previous studies have suggested that the motor cortex is involved in voluntary jaw movement in monkey [9,35,36]. This supports the findings of an fMRI study by Tamura et al. [31] which showed that the primary motor and sensory cortices exhibited remarkable activity with clenching.

In this study, a tendency toward an increase in OxyHb in the primary motor and sensory cortices was observed with increase in intensity of clenching. This result was similar to the findings of Nambu [23] for finger tapping, in which the primary motor cortex contralateral to the testing site was activated with increase in force.

Non-human primate studies on corticomotor function have shown that a number of cortical and sub-cortical motor areas contain cells whose discharge rates correlate with the parameters of the movement being executed, including force, direction and frequency of movement [1,2,6]. Previous studies using recording of neuronal signal activity during jaw movement have suggested that many primary motor cortex neurons show movement-related activity and contribute to the control of jaw movement and biting force. Yoshino et al. [36] observed that all primary motor cortex neurons showed movement-related activity and reciprocal change in discharge rate between the closing and opening phases, thereby suggesting that the facial area of the primary motor cortex is involved in control of jaw movement, especially in contraction of the masticatory muscles. Weijis and Dantuma [34], reported that level of masseter muscle activity increased with hard foods. Intensity of afferent-encoded information from the peri-

odontium increases with strength of clenching [36]. In addition, Inoue reported that the cerebral masticatory area and motor cortex facial area in the primary motor cortex were involved in the start, execution and control of voluntary movements such as clenching and mastication [11,22]. This indicates that increase in clenching intensity results in increased activity in the primary motor cortex.

Earlier studies on jaw movement have suggested that oral sensory information ascended into the sensory cortex, thus controlling jaw movement and discrimination of food states in monkey [18] and cat [8]. Moreover, given that there are cortico-cortical projections of the sensory cortex to the motor cortex [37], it is reasonable to assume that sensory information is involved in the control of clenching intensity, either directly or indirectly, and that the sensory cortex region was activated in the clenching task in this study. On the other hand, sensory information from periodontal receptors [14] was transmitted to the primary sensory cortex via the trigeminal ganglion [15], with subsequent activation of the primary sensory cortex. Sensory information not only from the periodontal ligament (predominantly via the maxillary and inferior alveolar nerve branches of the trigeminal nerve), but also from the dental pulp, gingiva, palatal mucosa, lips and skin of the jaw has been reported to increase with increase in clenching intensity [11]. Therefore, with increase in clenching intensity, the activity of the primary sensory cortex increases.

In this study, an increase in right masseter muscle activity was observed with increase in intensity of clenching. Voluntary contraction of the masseter muscle occurs with clenching [14], with this activity located predominantly on the working side [25]. As the right masseter muscle contracted in this study, excitation of the masseter muscle spindle appeared to be transmitted with crossed-laterality to the primary motor cortex [3], thus activating the contralateral primary motor cortex.

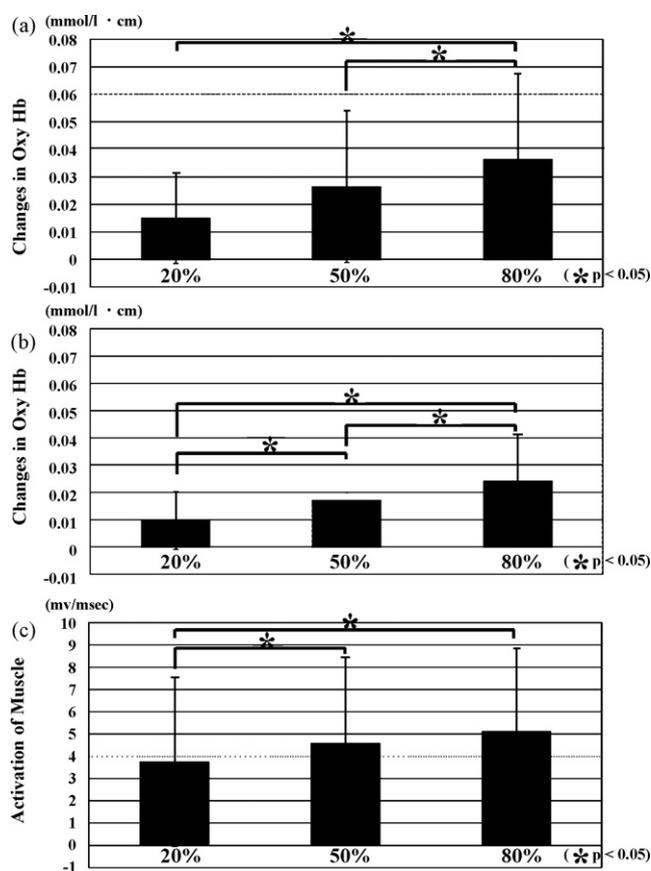


Fig. 3. Changes in OxyHb in the cerebral cortex and activation of muscle respond to clenching and clenching intensity. A significant increase was observed in OxyHb in the primary motor cortex between at 80% and both 20% and 50% clenching intensity (a). A significant increase was observed in OxyHb in the primary sensory cortex between all intensities measured (b). A significant increase was observed in activity in the right masseter muscle between at 20% and both 50% and 80% clenching intensity (c).

Level of consciousness and concentration have been shown to increase with gum-chewing in human [13]. A correlation has been shown between chewing force and IQ in children [4,5]. Furthermore, mastication has been shown to delay the effect of aging on brain function [17]. Shibusawa et al. [28] have reported that increased hardness of food induced activation of the prefrontal cortex. All these studies suggest that appropriate masticatory and occlusal forces and stimulation help maintain and enhance brain function. In this study, we observed increases in OxyHb in the prefrontal cortex during harder clenching. These observations indicate that clenching induces activation of the prefrontal cortex, suggesting that mastication affects brain function.

In summary, activation of the primary motor and sensory cortices was associated with clenching in all subjects, irrespective of intensity of clenching. Almost all of the subjects showed a tendency toward an increase in OxyHb in the primary motor and sensory cortices as intensity of clenching increased. The results suggest that clenching elicits activation of both the primary motor and sensory cortices and that intensity of clenching influences activation levels in the brain.

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